

Open Research Online

The Open University's repository of research publications and other research outputs

Developing Metacognitive Skills in Secondary School Students

Thesis

How to cite:

Panganayi, Mupenyu Felix (2018). Developing Metacognitive Skills in Secondary School Students. EdD thesis The Open University.

For guidance on citations see [FAQs](#).

© 2018 The Author



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

Version: Version of Record

Link(s) to article on publisher's website:

<http://dx.doi.org/doi:10.21954/ou.ro.0000e3d1>

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data [policy](#) on reuse of materials please consult the policies page.

oro.open.ac.uk

Felix Mupenyu Panganayi
DipTech; BSc.Ed; BAcc (Hons); MA.Ed

‘Developing Metacognitive Skills in
Secondary School students’

Submitted for Doctorate of Education

The Open University

Discipline: Education

January 2018

Abstract

The research in this thesis focussed on whether metacognitive instructional methods can support the development of metacognitive skills (MS) awareness, and student achievement in secondary school students during problem solving in stoichiometry. The research involved four studies. The first was a quasi-experiment using the metacognitive skills framework (MSF) to support students. The intervention was conducted by a chemistry teacher, for one hour/week over three weeks, with pre- and post-test assessments. There was a control group ($N=19$) and an experimental group ($N=22$). There was no significant improvement in MS awareness, however, there was a significant improvement in stoichiometric achievement for the experimental, but not the control group.

Study 2 involved a comparison of MSF ($N=21$); metacognitive skills modelling (MSM; $N=17$), another less explicit instructional method; and a control group ($N=23$). Similar measures to those in Study 1 were used. The three groups failed to show significant improvement over time in MS awareness. However, the MSF and Control groups showed significant improvement in stoichiometric achievement. Study 3 concerned the students' MS awareness and use. An interview group was drawn from each of the three conditions and was asked a series of semi-structured questions. The MSF and control groups gave answers which suggested higher MS awareness and use compared to MSM group. This was not expected and consequently Study 4 was conducted.

Study 4 involved interviews with the teachers of the students in the three conditions. Some of the findings in Study 2 could be explained by the control group teacher supporting MS awareness and use, and that this group had a public examination in chemistry shortly after the study.

Thus, the findings from this research suggest that use of the MSF is associated with increased scores in stoichiometry. However, further research is needed to better understand the effects of interventions on the enhancement of metacognitive skills awareness and use.

Acknowledgements

I would like to express my deepest gratitude and appreciation for the relentless and sterling support, encouragement and motivation I received from my first supervisor Professor David Messer. His generosity with supervision time was exceptional and requires a special mention; especially time availed for support via Skype and what's app calls. Those iterative redrafts in quest for a refined end product will always be remembered! I would also like to thank my initial second supervisor Dr Cindy Kerawalla for her support during my first year and part of second year. And to Dr Val Critten, my second supervisor who came much later on into this journey, thank you very much for your support especially with the qualitative analysis, structuring and organisation of the final draft of the thesis.

To my wonderful wife Miriam; I would like to thank you for your unwavering support on this journey. Without your encouragement, emotional and financial support, this academic enterprise would not have been achievable. May God richly bless you. And to my wonderful children; Primrose and Dylan thank you for being there when I needed to be cheered on! Dylan, I liked your sense of curiosity as you repeatedly asked what my research was all about so that you could tell your friends! To my mother and my aunt who made it a point to pray for me when they didn't know what kept me awake into the very late hours of the morning; thank you for your relentless prayers!

And to my staff at WISETECH COLLEGE, especially Keitumetsi, thank you for your support when I could not attend school assemblies because of late nights.

Paul Jensen, 'rafiki', thank you for introducing me to the academic world of metacognition. Though you humbly deny it, you are partly the reason why I decided to embark on this academic journey!

Finally I would like to express my heartfelt gratitude to:

- The leadership of the schools where I conducted my research
- The amazing and very friendly students and teachers who participated in this research
- The Ministry of Education, Zimbabwe for granting me permission to carry out part of my research at one the schools under its jurisdiction.

Contents

Title page	1
Abstract	2
Acknowledgements	3
Contents	4
Appendices	8
References	8
List of Tables	9
Table of figures	9

Chapter 1: Introduction: Setting the Scene

1.1 Introduction	10
1.2 The origins and concept of met cognition	10
1.2.1 Early work on metacognition	10
1.2.2 The concept of met cognition	11
1.3 Perceived benefits of metacognitive skills in problem-solving	12
1.4 The cultural context of the study	17
1.5 Summary	18

Chapter 2: Literature review: Previous Research and Theories about Metacognition

2.1 Self-regulation and met cognition	20
2.1.1. Self-regulated learning theory	25
2.2 Different Forms and Levels of Met cognition	27
2.2.1 Metacognitive Knowledge (MK)	27
2.2.2 Metacognitive skills (MS)	28
2.3 Metacognitive Theories and Student Learning	30
2.3.1 Types of metacognitive theories	31
2.3.2 Section summary	34
2.4 Ways to improve met cognition	35
2.4.1 General Teaching Methods that have been used to promote metacognition.	36
2.4.2 Metacognitive training in secondary and tertiary education	38
2.4.3 Rationale for Further Research on Metacognition in Secondary School Chemistry.	42
2.4.4. Secondary school chemistry: Metacognitive skills training.	43
2.5 Chapter summary and rationale for the research questions	46
2.5.1 Research Questions.	46
2.5.2 Chapter Summary.	46

Chapter 3: Research Methods, Research Assumptions and Research Paradigms

3.1 Introduction	48
3.2 From ontological and epistemological assumptions to pragmatism	48
3.2.1 Epistemological Assumptions and Research Paradigms	49
3.2.1.1 The nature of research paradigms	49
3.3 Methodological Assumptions	51
3.3.1 Choice of quasi-experimental research design	52
3.3.2. Data collection Methods	53
3.3.2.1 Metacognitive Awareness Inventory (MCAI)	53
3.3.2.2 Problem-solving Tasks in Stoichiometry (PSTs)	56
3.3.2.3 Group Interview	56
3.3.2.4. Semi-structured Interview	59
3.4 Ethical considerations	61
3.5 Chapter Summary	63

Chapter 4: Study1: The effect of instructional intervention on students' metacognitive skills and achievement during problem-solving in IGCSE stoichiometry.

4.1 Introduction: Summary review of research on metacognitive instructional methods.	65
4.1.1 Using the Metacognitive Skills Framework as an Instructional Method.	69
4.1.2. Assessing metacognitive skills awareness and achievement in stoichiometry.	71
4.1.2.1 Metacognitive Awareness Inventory (MCAI)	71
4.1.2.2. Problem-solving Tasks (PSTs)	73
4.1.3 Summary	73
4.2 Study 1 Method	74
4.2.2 Participants	74
4.2.3 Measures	74
4.2.4 Procedure	75
4.2.5 Intervention	75
4.3 Results of Study 1	76
4.4 Discussion	79
4.4.1 The way the MSF could have increased students' achievement in stoichiometry	81
4.5 Summary	82

Chapter 5: Study 2: Comparing instructional effectiveness of MSF and MSM in developing students' MS and achievement in stoichiometry problem-solving.

5.1 Introduction and literature review.	84
5.1.1 Metacognitive Skills Framework and Metacognitive Skills Modelling.	84
5.1.2 Well-defined and ill-defined problems.	86
5.1.3 The relative contribution of the components of metacognitive skills to problem-solving.	87
5.2 Methodology	89
5.2.1 Method	89
5.2.1.1 Participants	89
5.2.2 Measures	90
5.2.3 Procedure	90
5.3 Results of Study 2	93
5.3.1 Data analysis	93
5.3.2 The MCAI Scores of the Three Groups	93
5.3.3 The Four Components of MCAI (PCME) and their Percentage change over time.	95
5.3.4 Chemistry Problem-solving Task Scores (PSTs) for the three groups	97
5.3.5 Correlation between MCAI scores and PSTs score	98
5.4 Discussion	100
5.4.1 Did the instructional intervention make a difference in metacognitive awareness.	101
5.4.2 Which instructional intervention was more effective in raising achievement?	102
5.4.3 Was there a correlation between problem-solving achievement scores and MCAI scores?	102
5.5 Limitations	104
5.6 Implications for teaching and learning	104
5.7 Summary and Future Research	105

Chapter 6: Study 3: Assessing similarities/differences of metacognitive skills and motivation of students of stoichiometry.

6.1 Introduction and literature review	107
6.1.1. Similarity of metacognitive skills.	108
6.1.2. The use of different components of metacognitive skills awareness cross the three groups.	108
6.1.3. Motivational orientation	110
6.1.4 Assessing evidence	113
6.2 Study 3 Method	115
6.2.1 Participants	115
6.2.2 Procedure	116
6.3 Results: Transcription and analysis of results	116

6.3.1 Planning	118
6.3.2 Monitoring	119
6.3.3 Control	120
6.3.4 Evaluation	122
6.3.5 Motivation	123
6.4 Discussion	124
6.4.1 Planning strategies	124
6.4.2 Monitoring strategies	125
6.4.3 Control strategies	127
6.4.4 Evaluation strategies	128
6.4.5 Motivation	129
6.5 Summary and Conclusion	130

Chapter 7: Study 4: Insights provided by teachers' interviews about how they support students with metacognitive strategies

7.1 Introduction and Literature review	132
7.1.1 General teaching approach adopted by teachers of stoichiometry	133
7.1.2 Algorithmic and conceptual teaching approaches	134
7.1.3 Motivation strategies	136
7.2 Study 4 Method	138
7.2.1 Participants	138
7.2.2 Procedure	138
7.3 Results: Transcription and analysis of results	139
7.3.1 Transcription and analysis	139
7.3.2 What instructional strategies were used by the teachers of the three groups to help their students learn stoichiometry?	139
7.3.3 What instructional strategies did the teachers of the three groups use to help their students use metacognitive strategies?	139
7.3.4 What instructional strategies did the teachers of the three groups use to motivate students when teaching stoichiometry?	140
7.3.5 What instructional strategies did the teachers of the three groups use to motivate students when teaching stoichiometry?	143
7.4 Discussion	144
7.4.1 Did the teachers of the three groups use the similar strategies to teach stoichiometry?	145
7.4.2 Did all the teachers of the three groups use metacognitive strategies when teaching stoichiometry and what were these strategies?	146
7.4.3 Did all the teachers of the three groups use similar strategies to motivate students when teaching stoichiometry?	149
7.4.4 Relations between Teaching Strategies with Student Metacognition and PST scores.	151
7.5 Summary and conclusion	152

Chapter 8: Discussion

8.1 Introduction	155
8.2 Study 1	156
8.3 Study 2	157
8.4 Study 3	160
8.5 Study 4	163
8.5.1 Did the teachers of the three groups use the similar strategies to teach stoichiometry?	164
8.6 Overall conclusion	166
8.7 Implications for teaching	168
8.8 Limitations	171
8.9 Further research	174
8.10 Conclusion	175

References	177
------------	-----

Appendices

Appendix 1: Metacognitive Skills Framework	188
Appendix 2: Metacognitive Skills Modelling	189
Appendix 3: Metacognitive Activities Inventory (MCAI)	190
Appendix 4: Students' Semi-Structured Interviews	192
Appendix 5: Teachers' Semi-Structured Interviews	194
Appendix 6: Pre-test Problem-solving Task	195
Appendix 7: Teachers' Practice Problem-solving Task	196
Appendix 8: Post-test Problem-solving Task	197
Appendix 9: Stoichiometry Problem-solving Tasks	198
Appendix 10: Letter of information to participant students and parents/guardians	201
Appendix 11: Informed consent form for parents	203
Appendix 12: Informed consent form for students	204
Appendix 13: Letter of information to the participating teacher	205
Appendix 14: Informed consent form for participating teacher	206
Appendix 15: Letter of information to the Head Teacher	207
Appendix 16: Questions and students' responses on planning	208
Appendix 17: Questions and students' responses on monitoring	209
Appendix 18: Questions and students' responses on control	210
Appendix 19: Questions and students' responses on evaluation	211
Appendix 20: Questions and students' responses on motivation	212
Appendix 21: Questions and teachers' responses/comments	213

List of tables

Chapter 4

4.1 MCAI mean percentage scores, standard deviations, skewness and kurtosis of the experimental and control groups	77
4.2 Mean PSTs percentage scores, standard deviation, skewness and kurtosis from the chemistry questions for the control and experimental groups.	78

Chapter 5

5.1 The MCAI mean percentage scores , standard deviations, skewness and kurtosis of the experimental and control groups	93
5.2 The PST mean percentage scores, standard deviations, skewness and kurtosis of the experimental and control groups.	95
5.3 Percentage change of MCAI and PST scores over time for all three groups.	97
5.4 Comparison of PCME Percentage change over time for all groups	98
5.5 Pearson's correlation between MCAI and PSTs scores for all conditions	98
5.6 Pearson's correlation between PMCE and PSTs scores for all conditions	99

Table of figures

Chapter 2

2.1 Fig 1 Components of self-regulation according to Schraw and Moshman	22
2.1 Fig 2 Relational nexus of components of self-regulated learning	24

Chapter 1: Setting the Scene

In this chapter I provide a personal account about my interest in metacognition and present a brief historical perspective about the origins and early use of the concept. In addition, I distinguish between the two components of metacognition; metacognitive knowledge (MK) and metacognitive skills (MS). I also provide an overview of the focus of the research reported in this thesis. In chapter 2 there will be a more detailed consideration of research related to metacognition which is relevant to this thesis.

1.1 Introduction: My Interest in Metacognition

After over twenty years as a teacher of science with a major in chemistry, I decided to pursue a Master of Education degree with the Open University. While studying ED841, a course on 'Understanding Children's development and learning', I became interested in metacognition in general and in metacognitive skills in particular, as this appeared to carry the potential to provide a plausible answer to a question that had bothered me for over twenty years; how can I improve my students' problem-solving skills in numerical chemistry, technically referred to as stoichiometry? Stoichiometry is a branch of chemistry involved with the use of quantitative relationships between reactants and/or products in a chemical reaction to determine desired quantitative data, such as mass and moles. These relationships are governed by the natural laws of the conservation of mass and the law of the conservation of matter.

1.2 The origin and concept of metacognition

1.2.1 Early work on metacognition

The term metacognition is mostly associated with John Flavell (1979) and he is regarded as the major pioneering researcher in this field. He used the term

metacognition in reference to an individual's understanding of his/her own thinking and learning. Flavell (1979) suggested that metacognition consisted of two components; metacognitive knowledge and metacognitive experiences or regulation. A.L. Brown (1987) is another notable figure in the field of metacognition. Building on Flavell's (1979) model of metacognition, Brown (1987) suggested that metacognition consists of knowledge of cognition and regulation of cognition. There are many more researchers who have made an impact on our understanding of metacognition (e.g. Kuhn, 1991, 2000; Schraw and Moshman, 1995; Butler and Winne, 1995).

1.2.2 The concept of metacognition

Metacognition is generally recognised as consisting of knowledge of cognition and regulation of cognition (Schraw, 1998; Brown, 1987). There is no common definition of metacognition, however the construct often has been described as thinking about one's own thinking (Rickey and Stacey, 2000), knowledge of and regulation of one's own cognitive system (Brown, 1987), and the capacity to reflect upon one's actions and thoughts (Schraw, 2001) while Flavell (1979) defined it as cognition of cognition that serves two basic functions, namely, the monitoring and control of cognition. Weinert (1987, p8) wrote that metacognition is 'second-order cognition; thoughts about thoughts, knowledge about knowledge, or reflections about reflections' and Kuhn (2000, p178) defines metacognition as 'cognition that reflects on, monitors and regulates first order cognition'. Taylor (1999) broadly defines metacognition as a process where individuals think about their own thinking and knowing what they know and don't know.

For the purpose of this study, I subscribe to the definition suggested by Brown and Flavell. I consider metacognition to involve two fundamental processes, namely, the knowledge of cognition and the regulation of cognition; these two processes

encompass much of the description of metacognition suggested by the other authors. In literature, metacognition is generally divided into metacognitive knowledge (MK, also known as knowledge of cognition) and metacognitive skills (MS, also referred to as regulation of cognition; Schraw and Moshman, 1995). Briefly, metacognitive knowledge is concerned with knowledge of one's self as a learner, knowledge of how to perform a task, knowledge of strategies and how and when to apply them during learning or task performance (Schraw and Moshman, 1995; Flavell, 1979). Metacognitive skills are strategies concerned with the regulation of cognition during a learning activity (Brown, 1987) and these strategies can be applied consciously or automatically to control cognitive processes before, at the beginning, in the middle or at the end of a cognitive activity (Flavell, 1979). Metacognitive skills consist of four components; planning, monitoring, control and evaluation (Whitebread, Coltman, Pasternak, Sangster, Grau, Bingham, Almeqdad and Demetriou, 2009; Schraw and Moshman, 1995). This is covered in more detail in Chapter 2.

1.3 Perceived benefits of metacognitive skills in problem-solving

Why metacognition in chemistry? Metacognitive skills in science education are generally linked to reading, problem-solving, inquiry and writing (Veenman, 2012; Schraw et al., 1995). Metacognition has also been found to help students improve their problem-solving skills (Rozencajg, 2003; Howard, McGee, Shia and Hong 2001; Schraw et al., 1995). A number of studies reported in science education journals and particularly in the Journal of Chemical Education, have emphasised the relevance and importance of metacognition to learning chemistry in general and to problem-solving in particular (Schraw, Crippen, Hartley, 2006; Paris and Paris, 2001; Pintrich, 2000; Rickey and Stacy, 2000; Francisco and Nicholl, 1998). Tsai (2001) describes it as key to achieving the mastery of chemistry.

Swanson (1990) investigated the effect of different levels of metacognitive knowledge on problem-solving skills in children and found that those children who exhibited higher metacognitive levels were found to outperform those with lower metacognitive knowledge irrespective of their aptitude in the subject. These findings suggest that general aptitude and metacognition are independent and lower aptitude could be compensated for by higher metacognitive activity (Pennequin, Sorel, Nanty and Fontaine 2010; Swanson, 1990). In addition, there is research that suggests students who show superior learning skills employ metacognitive strategies to complete learning tasks and are in the habit of thinking through the task demands well before they attempt the task (Efklides, 2005; Scruggs, Mastropieri, Monson, and Jorgenson, 1985). It is also reported that when students are taught metacognitive strategies there is increased learning which comes as a direct result of instruction (Schraw et al., 2006; Scruggs et al., 1985).

Scruggs et al. (1985) claim that students who show superior learning skills employ metacognitive strategies to complete learning tasks. However, Scruggs et al. (1985) and other researchers have not suggested instructional methods which can be used to achieve this in the classroom.

In the last three decades research on metacognition in relation to science education has experienced a steady growth and has expanded to include fields focusing on the mastery of basic ideas in science and conceptual change (Zohar and Barzilai, 2013). Schraw et al., (2006, p. 117) observe that:

“effective science instruction must not only increase learning but also help students develop the metacognitive skills needed to succeed at higher levels of science and to construct their conceptual knowledge and procedural strategies when necessary”.

Schraw et al., (2006) recognise that the acquisition of factual knowledge alone is not sufficient to produce an effective learner, rather students must understand the how, why and when of learning. From my experience, teachers have the tendency to focus on content rather than on learning strategies, but training students to be able to set up their own academic goals and put in place strategies for achieving them may help students to develop a more realistic self-awareness about their learning styles and develop learning strategies to overcome learning deficiencies (Haidar and Naqabi, 2008).

I believe that understanding how metacognition helps students will enable teachers or instructors to organise teaching and learning activities in a way that maximises students' use of their own knowledge and understanding. Three decades of research in the area of metacognition in general has shown that both typical and special needs pupils benefit from the awareness and application of metacognitive skills in learning (Efklides, 2008). Although researchers recognize the importance of metacognition in teaching and learning, metacognitive strategies are rarely taught explicitly to students and yet there is an expectation from instructors that students must master content from the curriculum (McElwee, 2009).

It can be argued that teachers should be equipped with sound instructional methodologies or strategies that enable them to teach metacognitive skills and to this end my research investigated two instructional approaches to evaluate their effectiveness in developing and enhancing metacognitive skills use in International General Certificate of Secondary School Education (IGCSE) level stoichiometry. Teaching students how to learn equips them with transferrable skills that will be needed throughout their further education and career (Schraw et al., 2006). It is estimated that nearly 60% of factual knowledge disappears quite quickly within two to three years if it is not put to relevant use (Bahrick, 1984).

Teaching metacognitive skills to students gives them the potential to understand their own learning. While cognitive abilities are necessary for task performance, metacognitive skills allow students to understand how they perform a task (Gardener, 1987). Teaching metacognitive skills is believed to give students responsibility for the way in which they learn, rather than expecting them to be passive recipients of information; and in order to maximise the benefits of learning experiences pupils must be able to evaluate their own performance, isolate steps which they can take to help them to improve while working in a collaborative way with their teachers to decide on next steps (Scruggs et al., 1985).

It has been argued that secondary school students are generally not capable of developing self-reflective abilities without assistance; they need to be instructed, coached and consistently reminded (McElwee, 2009). However, it has been suggested that students can develop their metacognitive skills when they are taught questioning techniques to guide their thinking processes (McElwee, 2009). Researchers have noted that students can develop skills that allow them to think, reflect and question effectively (Ciardiello, 1998; Weir, 1998).

When students are taught how to generate effective questions this means that they can develop skills to analyze and synthesise, compare and contrast, and evaluate information or ideas (Weir, 1998). These are skills which could be applied to algorithmic numerical problem-solving tasks such as those found in stoichiometry where students must learn to raise what, why and how questions e.g. what does the problem require me to do, what do I know, or must I know, what strategy do I use, when and how do I use this strategy etc (Schraw et al., 2006; Rickey and Stacey, 2000; Scruggs et al., 1985).

There has been a lot of research on the benefits of training students across various subject domains to develop their metacognitive skills awareness but unfortunately, findings from previous research on metacognitive skills have not reported or identified effective instructional methods for the development and enhancement of the use of metacognitive skills (Zohar and Barzilai, 2013). In addition, the lack of robust and reliable instruments to assess the use of metacognitive skills has been one of the limiting factors in researching metacognition skills in science education and other areas (Sandi-Urena, Cooper and Stevens, 2011).

My research reported in this thesis has investigated the effect of instructional methods on the enhancement of metacognitive skills through problem-solving in stoichiometry. The research focused on stoichiometry because it is one of the most challenging concepts in chemistry out of six areas identified by researchers in chemistry education (Haider and Naqabi, 2008).

Two instructional approaches were compared; the metacognitive skills framework (MSF, Appendix 1) and metacognitive skills modelling by the teacher (MSM, Appendix 2). Previous research on metacognitive skills has not identified the effectiveness of instructional methods on the development and enhancement of the use of metacognitive skills. In addition, previous researchers have not investigated the components of metacognitive skills together, instead, many studies have been carried out to investigate components of metacognitive skills in isolation and the most studied component is self-monitoring followed by self-evaluation (Zohar and Barzilai, 2013). Research has not revealed the components of metacognition skills which contribute more to conceptual change and conceptual understanding (Zohar and Barzilai, 2013).

It would be beneficial for teachers to understand how each component of metacognitive skills contributes to learning in science and specifically in chemistry

which has been the least researched subject with respect to metacognition in general and metacognitive skills in particular (Zohar and Barzilai, 2013). Knowledge of how each component contributes to learning can help teachers plan learning tasks around these components in order to maximise learning. However, the lack of robust and reliable assessment instruments to measure the use of metacognitive skills has been one of the major limiting factors in researching metacognition skills in science education and other areas (Sandi-Urena et al., 2011).

1.4 The cultural context of the Study

The research reported in this thesis was carried out in Zimbabwe and it involved 16 year-old secondary school students studying chemistry following the University of Cambridge International General Certificate of Secondary School Education (IGCSE). This is equivalent to the General Certificate of Secondary School Education (GCSE) in the United Kingdom. Participating students were drawn from a private school (independent) and from a faith public school. Both schools followed the same chemistry curriculum i.e. University of Cambridge IGCSE. Both schools are non-selective schools, implying that there was a mix of abilities across the participating students. English is the medium of instruction in the Zimbabwe School system, so all participating students wrote, spoke and understood English to L1 level. While school cultures may differ, there is nothing in literature that suggests that this might have a bearing on students' metacognition awareness and use. Participating teachers were all educated to degree level and were majors in Chemistry. This is equivalent or the same as a UK three year university degree.

1.5 Summary

In this chapter I have explained my interest in metacognition as having been motivated by my quest for effective ways of helping students of chemistry improve their understanding of problem-solving in stoichiometry. I have also provided information about the origins of research about metacognition with a focus on the work of Flavell and others. A brief distinction between the two components of metacognition; metacognitive knowledge (MK) and metacognitive skills (MS) has been described.

In the next chapter, research relevant to my thesis will be considered in more detail. The next two chapters will set out the background to the research in this thesis. Chapter 2 begins with a description of the terms and concepts used in research on metacognition. The last part of the chapter involves an outline of relevant previous research and leads to the formulation of the research questions that are addressed in this thesis. Following this, in Chapter 3 there is a consideration of which general research paradigms are appropriate to address the three research questions, and then which methods are appropriate to address the research questions.

This thesis consists of four studies. Study 1 which is reported in Chapter 4 concerns the effectiveness of a metacognitive skills instructional method called Metacognitive Skills Framework (MSF, Appendix 1) in improving the students' achievement in stoichiometry and metacognitive skills awareness and use. Study 2 (reported in Chapter 5) was concerned with comparing the effectiveness of two metacognitive instructional methods; Metacognitive Skills Framework and Metacognitive Skills Modelling (MSM, Appendix 2) to extend our knowledge of the instructional techniques that could improve students' chemistry achievement and metacognitive skills awareness and use. Following the inconclusive findings from Study 2, it was

necessary to make further inquiries and this led to the design Study 3 and 4 reported in Chapter 6 and 7 respectively. The study in Chapter 6 was concerned with interviews with participants to better understand the students' perspectives about metacognition, while Study 4 reported in Chapter 7 involved interviews with the teachers who taught the three groups, in this way information was obtained about the teacher's perspectives about metacognition. The thesis concludes with a discussion (Chapter 8) where the findings from the four studies are pulled together.

Chapter 2: Previous research and theory about metacognition

It is generally acknowledged that the topic of metacognition is a complex one. Part of the reason for this is that there often is inconsistency about the definitions of the term; there are a large number of similarly worded terms and because there are different views about the way that metacognition is related to other nearby concepts, such as self-regulated learning. Therefore, the first part of this chapter contains an overview of concepts relevant to metacognition.

The first section (2.1) considers self-regulation, as it is sometimes considered to be a super-ordinate construct in relation to metacognition (Zimmerman, 2000; Boekaerts, 1999; Butler and Winne, 1995; Schraw and Moshman, 1995) and self-regulated learning is often seen as an important way to increase student's problem-solving abilities (Zimmerman, 2000; Schraw and Moshman, 1995). This is followed by an outline in section 2.2 of different perspectives about the components of metacognition; these concepts are relevant to research into metacognition and to increasing students' metacognitive skills. Section 2.3 is concerned with metacognitive theories and their relevance to learning. Next, in section 2.4 there is a review of previous research about metacognition and examples of instructional methods used to promote metacognition. This leads to the last section which summarises the chapter and explains the research questions addressed in this thesis.

2.1 Self-regulation and Metacognition

Self-regulation and self-regulated learning are concepts closely related to metacognition and consequently are important areas to consider in relation to finding ways to improve students' problem-solving in stoichiometry (see Chapter 1). In this section, self-regulation (SR) and self-regulated learning (SRL) are defined. This is

followed by the description of Schraw and Moshman's (1995) view about the position of metacognition as a sub-component of self-regulation. The link between self-regulation and metacognition in general is discussed.

Researchers distinguish between self-regulation and self-regulated learning (Dinsmore, 2017, 2008; Schraw et al., 2006; Zimmerman, 2000; Boekaerts, 1999; Butler and Winne, 1995; Schraw and Moshman, 1995). Boekaerts (1999) suggests that self-regulation is a process in which an individual has the ability to develop personal knowledge, knowledge skills, perspectives and attitudes 'which can be transferred from one learning context to another and from learning situations in which this information has been acquired to a leisure and work context' (p.446).

On the other hand, self-regulated learning is described as a concept related to the learner's capability to comprehend and regulate his/her learning situation (Schraw et al, 2006); and for this to happen, it is suggested that the individual learner must set goals and choose strategies, implement the learning strategies and check on how well the movement towards those goals is progressing (Schunk, 1996; Butler and Winne, 1995). As can be seen, many of these ideas involve metacognitive processes.

Most research appears to have focussed on a broad enquiry into self-regulation during task performance. Zimmerman (2000), Butler and Winne (1995) agree with Schraw and Moshman (1995) that SRL is a process involving cognitive, metacognitive and motivational factors. While SRL is a broad concept, it is generally described as a process during which individual students are actively engaged in the monitoring and controlling of their own performance during the execution of a task (Fernandez and Jamet, 2017; Whitebread et al., 2009; Schraw et al., 2006; Pintrich, 2000; Zimmerman, 2000; Winne and Hadwin, 1998). Schraw et al. (2006) suggest that self-regulated students learn more with less effort because they are able to deploy resources more efficiently.

Different researchers have expressed differing views on how metacognition is related to self-regulation with some researchers considering metacognition a subcomponent of self-regulation (Schraw et al., 2006; Winne, 1996; Zimmerman, 1995) and others considering self-regulation as a subcomponent of metacognition (Kluwe, 1987; Brown and DeLoache, 1978). For the purpose of this study, I subscribe to the theoretical position proposed by Schraw et al. (2006) which considers self-regulation as a concept super-ordinate to metacognition and this is also the view held by major contributors to the study of this area (Zimmerman, 2000; Boekaerts, 1999; Butler and Winne, 1995). The authors describe self-regulation as involving cognition, metacognition and motivation and this is similar to a proposition made by Flavell (1979).

Below shows a summary of Schraw and Moshman's (1995) conceptualisation of self-regulated learning.

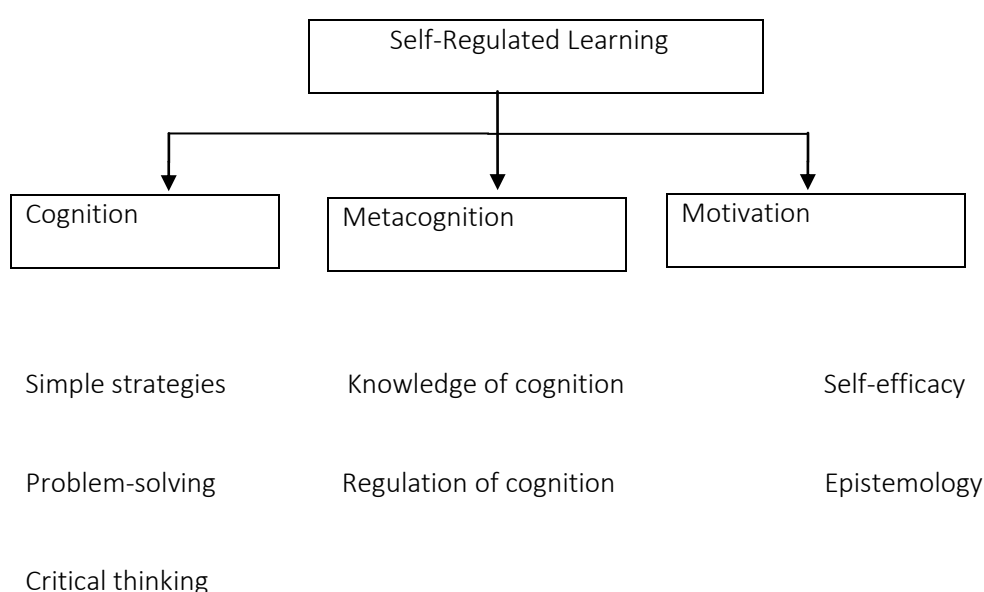


Figure 1: Components of self-regulation according to Schraw et al. (2006)

The above model of self-regulated learning shows how Schraw et al. conceptualized self-regulated learning. In Fig 1, Schraw and Moshman (1995) presented self-regulated learning as super-ordinate construct to metacognition, motivation and cognition. The

model also shows a direct interconnection between cognition and motivation. The argument for this is that students need to be motivated in order to engage in a cognitive activity. However, the model does not show how metacognition is connected to cognition and motivation. The model shows that the relevant cognition for self-regulated learning involves simple strategies, problem-solving and critical thinking skills; and the motivation component involves the learners' self-efficacy and their epistemological beliefs. Schraw et al. proposed that metacognitive activities are connected with cognition through simple strategies and with motivation through self-efficacy and epistemological beliefs. These connections were not specified in their model depicted in Fig 1, and for this reason I decided to develop this model to show how I see the links between cognition, metacognition and motivation. I provide a brief description of the model shown in Fig 2 below to highlight how cognition, metacognition and motivation collectively inform self-regulated learning.

The following concept map shows my conceptualization of the interrelationships between the basic components of self-regulated learning.

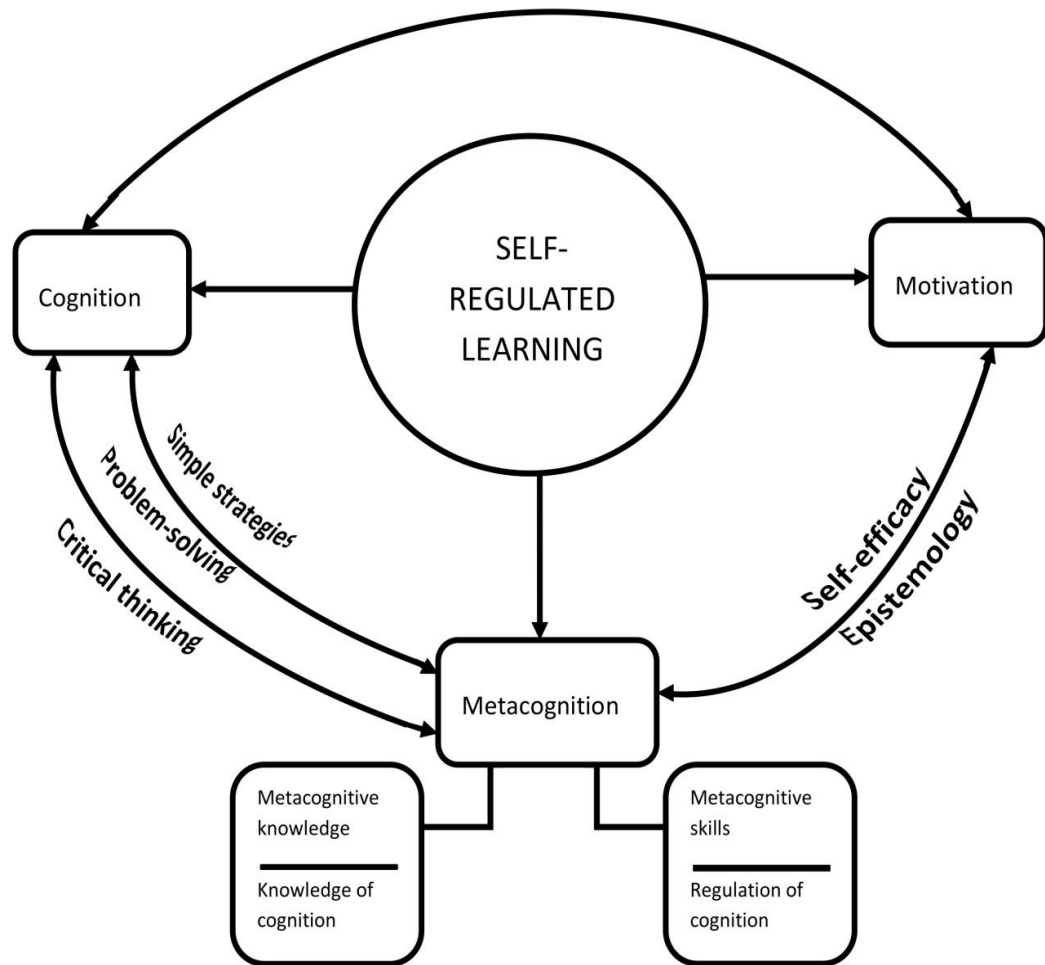


Fig 2 Relational nexus of components of self-regulated learning

Fig 2 represents my perspective of the how the components of self-regulated learning are linked. Fig 2 shows that motivation, cognition and metacognition do not work in isolation but together to enable self-regulated learning. A student who possess cognitive strategies and metacognitive skills and is not motivated to use them cannot achieve a high level of self-regulation in learning; and similarly, a student who is well motivated but does not possess cognitive and metacognitive skills cannot function at a high level of self-regulation (Zimmerman, 2000).

I assume that motivation depends on the learner's self-efficacy and epistemological beliefs as suggested by Schraw et al. (2006). Bandura (1997) describes self-efficacy as the extent to which an individual believes he/she can execute a specific task or achieve a given goal. It is suggested that self-efficacy is relevant for self-regulated learning because it determines the extent to which students can persistently stay engaged with a demanding learning task (Schraw et al., 2006). Students who possess high levels of self-efficacy are likely to engage with a challenging learning task and persist at the task despite initial setbacks, compared to students with low self-efficacy. Metacognition involves knowledge of cognition (metacognitive knowledge) and regulation of cognition (metacognitive skills). It follows that one cannot speak of metacognition and exclude cognition. Metacognition is cognition at meta level. When students engage in a learning activity, they employ cognitive strategies which are regulated by metacognition via the monitoring and the control function.

In summary, Fig 2 shows that self-regulated learners will be motivated to learn, when they have the appropriate cognitive abilities and are aware of what they know or should know. Although my research focused only on a subcomponent of metacognition, Figure 2 shows that cognition and motivation also play a part in the self-regulation of the learning process.

2.1.1. Self-regulated learning theory

This section describes and explains self-regulated learning theory (SRL) and links it to metacognition and to metacognitive skills in particular, thus providing its relevance to the study. Self-regulated learning theory originated in the social-cognitive learning theory of Albert Bandura. Bandura's theory was premised on the idea of *reciprocal determinism* which suggests that learning is a result of individual factors, the learning environment and the learner's learning behaviour (Schraw et al., 2006). The learning

environment refers to the quality of teaching, the quality of the feedback provided by teacher, availability and quality of learning information and the assistance provided by peers and parents (Bandura, 1997). The learner's belief system and attitude can be shaped by his/her learning experience which could be a function of other factors such as quality of provision. For instance, a learner who struggles to understand the principles of stoichiometry because of poor teaching can develop a belief that stoichiometry is difficult and may as a result, develop a negative attitude towards the topic or even the subject.

Self-regulated learning theory supposes that learning is controlled by cognitive factors, metacognitive and motivational factors (Schraw et al., 2006; Zimmerman, 2000; Butler and Winne, 1995). Problem-solving skills and learning can be directly influenced by metacognitive skills or self-regulatory skills (Veenman et al., 1997). During problem-solving activities, self-regulation can be seen in individual students at different stages of the problem-solving. Veenman et al. (1997) observe that during self-regulated activities, students go through various phases of problem-solving. The authors suggest that there is a problem analysis phase where the learner breaks down the problem in smaller chunks in order to understand the task demand; this is followed by the planning stage, then task execution stage and the evaluation stage. This is quite similar to the strategies identified as metacognitive skills. This account confirms the connection between metacognitive skills and self-regulation in learning. Learning activities that involve self-regulation are said to be representative of processes which are characteristic of metacognitive skills (Flavell, 1979; Brown, 1978).

2.2 Different Forms and Levels of Metacognition

Several different perspectives have been proposed about the salient cognitive processes involved in metacognition. Three of these perspectives are outlined in this section. The first sub-section, concerns metacognitive knowledge; what a person knows about his or her own cognition and the different forms that this might take (declarative, procedural and conditional knowledge).

The second sub-section concerns a related topic which is most relevant to the issues addressed in this thesis and this concerns different forms of metacognitive skills that are used in problem-solving and other activities (planning, monitoring, control and evaluation). The third sub-section concerns the different types of theories an individual has about their own cognition (tacit, explicit and formal/informal).

2.2.1 Metacognitive Knowledge (MK)

As previously stated, metacognition is usually divided into two subcomponents; knowledge of cognition and regulation of cognition/metacognitive skills (Schraw and Moshman, 1995; the term metacognitive skills will be used to refer to this topic in the rest of the thesis). Knowledge of cognition refers to what a person knows about his or her own cognition (Kuhn, 2000; Flavell, 1979; Brown, 1978). Schraw and Moshman (1995) suggest that there are three components of metacognitive knowledge;

- Declarative knowledge – this among other things covers what we know about ourselves as individual students and factors that affect us as individuals. For instance, students at secondary school level have self-knowledge of their memory limitations, so they choose a strategy to mitigate this limitation e.g. by making notes or highlight key points on a text. When in a classroom situation they have knowledge about their learning and this can inform the

choices they make concerning their future study and learning (Callender, Franco-Watkins and Roberts, 2016).

- Procedural knowledge- is concerned with the knowledge that a learner possesses about strategies and relevant procedures. For instance an adult learner may be in possession of strategies and procedures such as when to apply a certain method when solving a stoichiometry or physics problem or using mnemonics, summarising a text or skimming unimportant information, note taking (Schraw and Moshman, 1995).
- Conditional knowledge – this is knowledge about conditions under which specific strategies can be employed. Schraw et al. (2006) observe that an individual with a superior conditional knowledge finds it much easier to make an accurate assessment of the specific requirements and demands of a learning task and consequently is able to select strategies that are most suitable for the task at hand.

These ideas about metacognitive knowledge provide useful suggestions about the metacognitive processes involved in learning. However, from the perspectives of teachers, these distinctions are likely to be less relevant than the overall effects of an intervention which targets metacognitive skills. The next subsection considers a set of related ideas about theories of metacognition.

2.2.2 Metacognitive skills (MS)

As already discussed, metacognition is usually considered to involve metacognitive knowledge (section 2.2.1) and metacognitive skills (also referred to as the regulation of cognition). The latter is considered to involve use of strategies that regulate cognitive processes (Brown, 1987). More generally, metacognitive skills involve the deliberate actions that one takes in order to help thinking processes and learning

(Efklides, 2005) and they also form part of the so called “executive processes” (Brown, 1987) or metacognitive strategies (Lompscher, 1994). Metacognitive skills are generally involved with the monitoring of the understanding of task demands, putting in place a procedure for execution of the task, periodic review and controlling the cognitive processing in the event that it fails, and judging the quality of the results of the task processing to see if they meet the expected outcome (Veenman and Elshout, 1999).

It is important to remember that metacognitive skills are a subcomponent of the self-regulation process and care is taken not to reduce self-regulation to metacognitive skills alone because self-regulation also involves motivation, metacognitive knowledge and cognition (Efklides, 2005; Efklides, Niemivirta and Yamauchi, 2003). Schraw and Moshman, (1995) suggest that metacognitive skills (MS) cover three components: planning, monitoring and evaluation and more recently Whitebread et al. (2009) suggested a fourth component; control. Planning is concerned with choosing suitable strategies and distribution of intellectual resources, putting goals in place, predicting outcomes and choosing strategies (Schraw et al., 2006). Planning also includes activation of relevant background knowledge and time allocation to task implementation.

Monitoring involves online awareness of comprehension and performance (Zohar and Barzilai, 2013). It includes the self-testing skills necessary to control learning (Jacobse and Harskamp, 2012; Schraw et al., 2006). Self-monitoring during learning activities such as problem-solving is an essential part of self-regulated learning (de Bruin, Kok, Lobbestael, and de Grip, 2017). Evaluation entails appraising the end products and the efficiency of regulatory processes of one’s learning and thinking, (Zohar and Barzilai, 2013; Schraw et al., 2006;) for example through self-checking, re-evaluating one’s goals, revising predictions and consolidating intellectual gains. Control involves the

management of cognitive activities during learning, which include but not limited to making changes in the processes or strategies as a result of monitoring (Whitebread et al., 2009).

Research has shown that students who exhibit higher metacognitive functioning outperform those with lower metacognitive skills and this suggests that metacognitive training intervention can compensate for lower abilities (Swanson, 1990). Furthermore, developing metacognitive skills has been reported to promote a deep understanding during learning, helping students to make a transition from dependent to independent learning (Schraw et al., 2006).

Metacognitive knowledge (knowledge of cognition-declarative, procedural and conditional knowledge) has received more attention than the topic of the regulation of cognition by metacognitive skills (Yore and Treagust, 2006). Consequently, there is little evidence about the effect of specific instructional techniques on metacognitive skills (Zohar and Barzilai, 2013; Sandi-Urena et al., 2011). Therefore, research needs to be conducted to consider the possibility that the four components of metacognitive skills can provide concepts that could be very useful to teachers when trying to develop the metacognition of students. The use of metacognitive skills in teaching and research is considered in more detail in section 2.4.

2.3 Metacognitive Theories and Student Learning

This section considers the way that students theorise about their own learning as described by Schraw and Moshman (1995) in terms of three levels. The work of Schraw and Moshman (1995) will be the main reference in this section as there are few other studies on this particular topic. The link between metacognitive theories and self-regulation in learning is also discussed. The section concludes with a discussion where those who are able to theorize effectively about their metacognition

in general and their metacognitive skills in particular are believed to become more self-regulated and learn with less effort as observed in the previous section (Schraw et al., 2006).

What is the importance of metacognitive theories to the learner? Metacognitive theories help to bring together beliefs and ideas that pave way for individual students to make predictions or to control, and provide explanations of their own cognition or other people's cognition or just cognition at large (Montgomery, 1992; Flavell, 1992). An individual is likely to be an effective learner, if he or she understands that it requires one to retrieve relevant knowledge from memory, select the required strategy, allocating resources efficiently, make notes, draw tables or diagrams, review the effectiveness of the learning strategy and maintain high levels of self-motivation with the aim of achieving a more detailed comprehension of the learning matter. Metacognitive theories enable individual students to consolidate different areas of metacognition into a unified framework (Kuhn, 1991). This allows the learner to integrate metacognitive knowledge and regulatory metacognitive skills into a single unified conceptual framework which results in improved performance and understanding.

2.3.1 Types of metacognitive theories

Children as young as four are known to possess the ability to make theories about their own cognition (Flavell et al, 1992; Montgomery, 1992), although their theorizing remains a work in progress as they develop further, through their school career into adolescence and adulthood. Research findings indicate that theorizing improves both performance and understanding of one's performance (Schraw et al, 2006). Research findings also support the claim that a teaching process that focuses on self-talk and

peer-to-peer interaction rather than on learning outcomes, can help develop students' own metacognitive theorizing (Schraw and Moshman, 1995).

Schraw and Moshman (1995) proposed three types of metacognitive theories that individuals can have about their own cognition; tacit theories, explicit theories and informal theories. Tacit theories are described as those theories which an individual develops without much awareness (McCutcheon, 1992). The problem with tacit metacognitive theory is that individuals may not be aware of the existence of the theory itself (Schraw and Moshman, 1995). While tacit theory remains tacit, it may continue to exist even if it is false and fails to adjust to changes in the learning environment (Pine and Messer, 1999; Schraw and Moshman, 1995). Thus, it is likely to be a limitation on the effectiveness of learning and hence the need to train students to be aware of their own cognition and one way to do this is to explicitly teach metacognitive skills and assist them develop their tacit theories to become explicit. One way of doing this is to use an instructional tool such as the metacognitive skills framework (see section 2.4.4) which gives students an opportunity to develop a deliberate use of metacognitive skills during task performance in a learning situation.

Efklides (2005) suggests that metacognitive skills as part of a complex self-regulatory loop, form part of the 'executive function'. Although these processes operate within the subconscious realm, research has shown that metacognitive skills can be deliberately manipulated in order to develop and enhance them through training by teachers (Schraw et al., 2006). To this extend, it means that rather than leave within a formal learning environment to develop tacit metacognitive theories about their learning, teachers and peers can help theorize more effectively on their metacognitive skills in order to become more effective students.

Schraw and Moshman (1995) also identify and describe *informal* theories where students are partially aware of their beliefs or ideas about a concept, but they still do not have a fully constructed theoretical framework which allows them to unify and justify their beliefs and ideas. Those in possession of informal theories are likely to have a very basic awareness of their metacognitive knowledge, and so it could be important to help students develop their general metacognitive awareness and their metacognitive skills through deliberate instruction. This could also change through teacher or peer interaction where inaccurate aspects of the theory become modified and adapted to become functional, and these processes could help students advance towards the development of a personal learning theory (Schraw and Moshman, 1995).

Unlike informal theories, *formal* theories are those theories that are well structured and explicit. These include theories that are found in disciplines such as science and mathematics (Schraw and Moshman, 1995). Research into metacognition has not yet come up with what may constitute a formal theory of metacognition, but should such a theory come into existence, it could potentially have profound impact on the performance and understanding of performance of students (Schraw and Moshman, 1995).

Schraw and Moshman (1995) suggest that metacognitive theories are acquired from an individual's cultural environment through social learning and direct instruction in school. Clearly, this suggests that students can be aided through instruction to develop their metacognitive theory of learning. According to Schraw and Moshman (1995) there are at least two reasons why students *automatically* build metacognitive theories. Firstly, students want to regularise their expanding stock of cognitive skills and strategies, including their metacognitive knowledge about strategies, an

important step in becoming an effective learner. Secondly, students want to come to terms with what it means to be an effective strategic learner.

It is possible to conclude from the foregoing that if students are not aided and properly directed, metacognitive theorizing can remain at a primitive level, resulting in students adopting learning strategies that are maladapted and ineffective. It is therefore logical to observe that students should be made aware of their theoretical position in as far as metacognitive theories are concerned, in order for them to shift towards developing a valid personal theory of learning.

To summarise; this sub-section has considered three types of metacognitive theories and their characteristics and how they differ from each other. Tacit theories can exist without the individual's awareness and that as long as the theory remains tacit, it may persist even if it is false and maladaptive. Informal theories on the other hand, exist within the theorist's awareness and could potentially play a more important role in self-regulated learning. Formal theories give an explicit theoretical framework which allows students to understand and regulate their own cognition. What remains unknown, is what exactly makes up a formal metacognitive theory of one's cognition, the potential benefit would be that a learner could become more self-regulated, thus becoming a more efficient learner (Schraw and Moshman, 1995).

My research builds on the idea that deliberate and well-structured nurturing of metacognitive skills could have the potential to assist students to develop a personal theory of learning. In other words, explicit instruction of metacognitive skills can lead students to evolve from being tacit theorists to students with informal theories of learning, students with a well-developed personal theory of learning as problem solvers. Students will identify with what it means to be a good and effective problem solver in chemistry, particularly in the area of stoichiometry.

2.3.2 Section summary

Some of the major contributors to the field of metacognition (Schraw, et al., 2006; Winne, 1996; Schraw and Moshman, 1995; Zimmerman, 1995) subscribe to the theoretical framework that considers metacognition as a subcomponent of self-regulation. This positions metacognition as an important component of the learning process along with cognition and motivation. There are different perspectives about the components of met cognition, and these different perspectives are useful in suggesting targets for intervention and forms of metacognition that might be responsive to interventions. Metacognitive knowledge, as discussed in previous sections, is usually seen as consisting of declarative knowledge, procedural knowledge and conditional knowledge. All these different forms of knowledge are likely to be relevant to students' performance, and some could be easier to change than other ones. A further perspective concerns metacognitive skills such as planning, monitoring, and control evaluation which are readily translatable into teaching practices, pedagogy, that target students' metacognition.

A related set of ideas about metacognitive theories suggests that individuals can hold tacit theories, explicit theories and informal/formal theories; and a similar point can be made that these different types of theories are likely to be relevant to students' performance and some could be easier to change than other ones. In the next section there is an examination of evidence about using instructional methods to improve students' metacognition, both at tertiary and secondary school level.

2.4 Ways to Improve Metacognition

This section discusses current and past research on metacognition in general and metacognitive skills in particular in the field of science education at both tertiary and secondary school level. Domain specific research involving both metacognitive

knowledge and metacognitive skills has been carried out, although as will become apparent there is an absence of research into the effects of interventions which aim to develop metacognitive skills in relation to chemistry in secondary school students. Section 2.4.1 is concerned with general teaching methods; section 2.4.2 is concerned with metacognitive training in secondary and tertiary education, and section 2.4.3. is focussed on setting the rationale for further research on metacognition in secondary school chemistry.

2.4.1 General Teaching Methods that have been used to promote Metacognition.

Research indicates that general teaching methods in science instruction may promote metacognition and an improvement in the learning of science. Furthermore, these methods involve teaching approaches that have been tested and tried (Zepeda, Richey, Ronevich, and Nokes-Malach, 2015; Sand-Urena et al., 2011; Haidar and Naqabi, 2008; Schraw et al., 2006; Zimmerman, 2000). In this section there is an outline of enquiry based learning, collaboration, and the general use of questioning.

Schraw et al. (2006) consider that enquiry based learning provides the students with greater ownership and control of the learning process as they engage collaboratively with peers or teachers to share some problem-solving skills and strategies. Enquiry based learning is considered to promote the ability to reflect, which is an important aspect of metacognition, but not all enquiry science learning is authentic enquiry (Davis, 2003). Authentic enquiry requires time to develop, and is not usually achievable in most science lessons within a short period of time (Kipnis and Hofstein, 2008). Kipnis and Hofstein (2008), in a study involving the use of inquiry-type experiments to develop metacognitive skills of high school students in chemistry, found that students were able to employ metacognitive skills at different stages of task performance. But the study does not indicate that students were given training

on the use of metacognitive skills prior to carrying out inquiry activities. This is one example of studies where metacognitive skills are not explicitly taught, but are expected to develop through planned activities.

Another instructional practice considered to promote metacognition is collaboration. Collaborative learning is where organised groups of students are involved in sharing cognitive experiences (Schraw et al., 2006). Teacher-student and peer-peer collaboration is thought to promote better learning and increase self-regulation. Firstly, teacher or peer modelling allows task performance to be explicitly demonstrated, thus facilitating learning (Ellis, Denton and Bond, 2014; Archer and Hughes, 2011; Schunk 1996; Webb and Palincsar, 1996). Secondly, the support through collaboration between teachers and peers in modelling metacognition facilitates a dialogue in which scientific ideas and concepts are to be explored and in turn this allows the students' understanding to be evaluated and also to judge whether the learning outcomes have been met (Davis, 2003).

In another study to find out the effect of co-operative problem-based laboratory instruction on metacognition and problem-solving skills in chemistry, Sandi-Urena, Cooper and Stevens (2012) report that students working in a learning environment characterised by collaboration and reflection, developed metacognitive and problem-solving skills, despite the absence of direct and explicit strategy instruction. These researchers also claim that these skills are transferable to diverse situations, although they do not cite any relevant evidence to support their claim.

Another instructional strategy is the use of questions to generate reflection during learning activities and this was found to be the most common instructional strategy in the studies reviewed by Zohar and Barzilai (2013). Prompted reflection allows students to activate their metacognitive thinking.

Perhaps the most effective method in developing metacognition is problem-solving. In problem-solving, metacognitive skills could be an *input (learning strategy)* or an *outcome* (acquired during learning) of the learning process (Zohar and Barzilai, 2013) in which case problem-solving could be considered as an instructional method to promote metacognition. For example, a student working through Hess' cycle in chemistry must *plan* the routes of the reaction, allocate enthalpies to each route, check (*monitoring*) that the equations agree and if satisfied that everything is correct, proceeds to calculate the enthalpy of reaction, but if an error is identified, action to correct it (*control*) is taken before proceeding to calculate the enthalpy of the reaction. In this example, metacognitive skills are an input to problem-solving. If the overall solution is wrong, then the procedure needs to be reviewed (*evaluation*) for correctness. Problem-solving skills that are effective appear to be dependent on metacognitive skilfulness and a learning environment that promotes problem-solving skills (Gunstone, 1999).

The evidence reviewed in this section suggests that there is a range of general teaching methods and strategies that appear to enhance metacognitive skills. However, there is very little evaluative research on this relationship and it seems likely that these teaching methods and strategies are usually designed to be used over a long period and therefore are less suitable for targeting help in relation to a particular topic. In the next section research which more explicitly targets metacognition is discussed.

2.4.2 Metacognitive training in secondary and tertiary education

In this section I review studies that have been carried out to investigate ways to improve metacognitive skills at both secondary and tertiary level. However, more studies have been carried out at tertiary level than at secondary school. The section

starts with an overview of research in science education and then focuses on a limited number of previous studies that have been carried out to investigate ways to improve metacognitive skills in chemistry or subjects related to chemistry (e.g. mathematics and physics).

Zohar and Barzilai (2013) in a comprehensive review of secondary and tertiary education wished 'to map the current state of research in the field of metacognition in science education, to identify key trends, and to discern areas and questions for future research' (Zohar and Barzilai, p.2). The review reports metacognitive instructional practices and how frequently each instructional method was applied. The most frequently used instructional practice involved metacognitive prompts, which were generally used in order to remind students to activate their MS during science learning. The prompts were found to be metacognitive cues, questions or checklists (Zohar and Barzilai, 2013). Other frequently used instructional practices identified were reflective writing, practice and training; teacher led metacognitive discussion and explicit instruction. The least applied instructional practice was metacognitive modelling by the teacher.

Zohar and Barzilai (2013) also noted that metacognition was studied more frequently in some specific disciplines. Biology was the discipline most studied, followed by Physics, Chemistry and Earth Sciences. The highest number of studies was carried out in higher education with pre-school, elementary school and high school receiving the least attention. However, recent research indicates that there is no evidence to suggest the comparative effectiveness of given instructional methods on metacognitive skills, and this is thought to be partly due to the absence of sufficient tools to assess the effect of these instructional strategies (Zohar and Barzilai, 2013; Sandi-Urena et al., 2011).

There are a small number of previous investigations which are relevant to the focus of this thesis. Pennequin et al. (2010) carried out a study to find out if metacognition training could enhance metacognitive knowledge, metacognitive skills and mathematical problem-solving (which is relevant to stoichiometry) capacities of typical children aged between 8 and 10 years. The training programme took an interactive approach in accordance with Schraw's (1998) training model which is known as *regulatory check list* (RC) which encompasses three components of metacognitive skills; planning, monitoring and evaluation.

To improve knowledge of cognition, the study used Schraw's instructional method known as Strategy Evaluation Matrix (SEM), which gives students a choice of strategies to use for problem-solving and the conditions under which such strategies may be applied. Results from this study indicated that those children who were in the experimental group showed higher post-test metacognitive knowledge, metacognitive skills and problem-solving scores compared to those in the control group. In addition, the results also indicated that low achieving students benefited from metacognition training as they were able to make significant progress and were able to accurately complete the same number of problems on the post-test as other more able students on the pre-test. The study did not identify which aspects of metacognitive skills were involved and what their relative contribution to learning was. Although this was not the study's focus, such information could help teachers direct their instruction on specific components of metacognitive skills if their relative contribution to learning is known. Another problem of interpretation is that since the study targeted both metacognitive awareness (knowledge) and metacognitive strategies (skills), it is hard to tell which of the two components was responsible for the observed changes in learning.

In another study Sandi-Urena et al. (2011) investigated the effectiveness of intervention involving collaboration to promote college general chemistry students' metacognitive skills awareness and use. The study involved a quasi-experimental control and experimental design with 1001 participants. The MCAI questionnaire was used to assess the participants' metacognitive skills awareness and use. The treatment group, compared to the control group, showed a significant increase in metacognitive skills awareness as shown by the MCAI scores. A limitation of this study was that there was no assessment of any changes in chemistry abilities.

Cook, Kennedy and McGuire (2013), investigating the effect of teaching metacognitive learning strategies on performance in general chemistry course in a study involving 700 first-year students majoring in science, found that those students who received training on the use of metacognitive learning strategies improved their performance in their first examination by a whole grade. The training tool kit was a revised version of Bloom's Taxonomy, which is related to metacognitive skills. Bloom's Taxonomy is based on higher order thinking skills which involve analysis, evaluation, application, creativity. Again, as in the study by Pennequin et al. (2010), it is not clear which of the components of metacognition (MK or MS) were responsible for these observations which have an important implication for teaching and learning.

The research on the use of metacognitive instructional methods in teaching chemistry, though limited, indicates that gains in metacognition are possible as well as improvements in chemistry abilities. However, research has been mostly conducted either with secondary school students in mathematics or tertiary level students in chemistry. Apart from the research by Delvecchio (2011) and Haidar and Naqabi (2008) there appears to be an absence of research concerning stoichiometry, one of the most difficult topics facing secondary school pupils. This issue of a limited research base for chemistry is considered further in the next section.

2.4.3 Rationale for Further Research on Metacognition in Secondary School Chemistry.

Zohar and Barzilai (2013) noted a number of methodological problems that made the generalization of their findings difficult. Many studies that were reviewed did not employ experimental or quasi-experimental designs that included controls and pre/post-test measures. They also found that metacognition was

“integrated with additional instructional interventions such as collaborative learning, problem-solving and inquiry learning such that the specific contribution of metacognition could not be isolated” (Zohar and Barzilai, 2013, p.147).

Another problem identified was that difficulties in the assessment of metacognition were often ignored, with most of the studies reviewed employing self-report measures as a single source of data, despite the evidence showing that retrospective measures are known to have shown a poor correlation with concurrent measures of MS (Zohar and Barzilai, 2013; Cromley and Acevedo, 2006; Veenman, 2005, 2011).

In view of Zohar and Barzilai’s (2013) findings, it is clear that there is a need for studies within science education to be carried out within a specific science domain where the impact of MK or MS on learning can be clearly measured using a multi-method approach rather than relying on the traditional self-report measures. It is also essential that such studies involve a research design which can isolate MK or MS from the influence of other instructional interventions.

To enable the generalization of findings from such studies, it is necessary that such studies use experimental or quasi-experimental designs as these involve controls and pre-post measures. Chemistry is one of the science subject domains that have received little attention in the studies reviewed by Zohar and Barzilai (2013). This subject is often considered to be one of the most important sciences, given that all

those who desire to study medicine must study and pass the subject. The subject involves a lot of abstract concepts which sometimes require significant mental modelling in order to achieve conceptual understanding. Metacognition could help students develop a better conceptual understanding in chemistry.

2.4.4. Secondary school chemistry: Metacognitive skills training

Various teaching methods have been used to help develop metacognitive knowledge and metacognitive skills in science students. From my knowledge of the way that secondary students attempt stoichiometry problems and from my experience of what type of help is most effective, I decided to evaluate the effectiveness of two teaching methods which I thought had the potential to increase metacognitive skills and increase the ability to solve stoichiometry problems of secondary school students.

There were a number of reasons why I thought that targeting metacognitive skills (planning, monitoring, evaluation and control) could be effective with stoichiometry problems. In general, when students are engaged in solving stoichiometry problems in chemistry, they do a significant amount of planning. Students do this in order to set up problems and apply algorithms. As a result, they often address one of the metacognitive skills. However, my impression is that they do not utilize additional strategies; monitoring, control and evaluation, because they may perceive them as not being important for performing well in assessments (Haidar and Naqabi, 2008), hence it is important that the teaching of problem-solving strategies be made explicit via direct classroom instruction using tools such as the metacognitive skills framework (Appendix 1). Furthermore, research evidence suggests that explicit teaching strategies help students to develop metacognitive skills (Ellis et al., 2014). Characteristics of explicit teaching include direct instruction, modelling, explaining the

benefits of using the strategy and providing repeated opportunities for using the strategy in guided and independent practice formats (Scharlach, 2008).

There are two explicit methods of teaching that have been used in secondary school science and these are the ones I chose to evaluate; the Metacognitive Skills Framework (MSF) and Metacognitive Skills Modelling (MSM). MSF is an explicit 'pedagogical device to guide the teacher's instruction of problem-solving and students approaches to problem-solving' (Delvecchio, 2011). Delvecchio (2011) applied the metacognitive framework to study 'Students' use of metacognitive skills while problem-solving in High School Chemistry'. Delvecchio's version of the MSF consisted of three MS components; planning, monitoring and evaluation. I modified the framework (Appendix 1) by adding the control component which is an addition by Whitebread et al. (2009) to MS components. Thus, my MSF consists of planning, monitoring, control and evaluation.

MSF is an explicit instructional method which allows the teacher to explicitly guide students step by step in applying the strategies linked to the use of MS components during problem-solving. For example, to help students apply the MS planning component during problem-solving they could say to the students; *read the whole problem statement or question and underline key words, isolate relevant from irrelevant information* etc. The same procedure can be *repeated* for the other MS components (Chapter 4 describes the use of MSF in more detail).

Metacognitive Skills Modelling (MSM) is an explicit instructional approach which has been used in training metacognition where the teacher models the use of strategies to apply the four MS components. Modelling as an instructional method requires the teacher to demonstrate strategy use 'while simultaneously verbalizing one's thought processes or asking targeted questions during the demonstration' (Ellis et al., 2014,

p.418). Therefore, MSM requires the teacher to model the use of strategies for the application of MS components during problem-solving. For example, to demonstrate the strategies for the MS planning component, the teacher could say, *I read the question first* (and the teacher reads the question), *I then underline key words* (underlines key words), *I then isolate irrelevant information*, etc.

Therefore, the main difference between MSF and MSM is that in MSF the teacher tells students what to do and the students have the instructions written for them, while in MSM, the teacher performs the strategies by demonstrating what the students should do. I considered MSF to be more explicit than MSM and therefore expected it to be more effective than MSM because teaching a strategy in a more explicit way is likely to have a positive correlation with the students' achievement gains (Kistner, Rakoczy, and Otto, 2010). Details about MSM are found in Chapter 5.

In a study involving the use of metacognitive framework (see Chapter 4 section 4.1.1), Delvecchio (2011) investigated how this explicit metacognitive instructional method affected High school students' use of MS and their problem-solving abilities in some challenging chemistry problems. The study involved the use of self-report questionnaire about metacognitive skills (MCAI) and chemistry problem-solving tasks (PSTs) in a quasi-experimental design involving pre- and post-test measures. There were 39 participants; pilot (N=18) and experimental (N=21). The pilot group was used as the control. The results indicated no significant changes in MCAI mean scores between the control and experimental groups. However, the experimental group made significant gains in chemistry achievement compared to the control group. This study shows that the metacognitive framework helped students to make gains in chemistry achievement, but it did not help students improve their metacognitive skills according to the MCAI self-report measure.

2.5 Chapter Summary and Rationale for the Research Questions

2.5.1 Chapter Summary

The first part of this chapter provided an overview of some of the important terms used in research into metacognition. The topics included the relation between metacognition and self-regulated learning and different perspectives about the components of metacognition. Attention was paid to metacognitive skills as these appear to be a suitable target for interventions. The second part of this chapter provided an overview of research in metacognition where instructional methods such as collaborative learning and Schraw's (1998) strategy evaluation matrix (SEM) were used to provide metacognitive training at tertiary and secondary school level respectively.

A number of studies mostly at tertiary level, indicated that metacognitive training helps students increase metacognition and achievement. However, it was clear that there is lack of evidence of the effectiveness of metacognitive instructional strategies and hence the third and last part of this chapter proposed and considered the metacognitive skills framework and metacognitive skills modelling, two instructional methods which are instructional tools targeted at explicitly developing and enhancing all areas of metacognitive skills.

2.5.2 Research Questions.

As outlined in Chapter 1, the overall aim in carrying out research for this thesis was to help answer the question 'how can I improve my students' problem-solving skills in numerical chemistry (stoichiometry)?' A review of the relevant literature has shown that there are good indications that interventions directed at metacognitive skills can improve these skills and also improve students' performance in the relevant area of

learning. However, there is a lack of research into my particular area of interest, stoichiometry, and although there are uncertainties about how best to carry out an intervention, a reasonable case can be made for using an intervention based around metacognitive skills framework and modelling. Consequently, it was decided to formulate the first research question as:

- Do instructional interventions which teach metacognitive strategies during problem-solving activities in stoichiometry increase metacognitive skills awareness and use in secondary school students, as well as increase the ability to answer exam type questions?

The research that was carried out to answer the first research question produced some findings that were difficult to interpret. As a result, a second research question was formulated as:

- What insights do interviews with students and teachers provide about the teaching and learning of metacognitive skills strategies and student motivation?

This question was designed to help understand the findings relevant to the first research question, but it was also designed to provide more general information about metacognitive processes in the students and about the teaching of metacognitive skills by teachers. As noted in the review by Zohar and Barzilai (2013), an important research gap is investigation of teachers' use of metacognition to help their students. In the next chapter (Chapter 3), I discuss my transition from ontological and epistemological assumptions to pragmatism. This is followed by a section on methodology where I discuss my choice of research design and methods of data collection.

Chapter 3: Research Methods, Research Assumptions, Choice of Methodology and Methods

3.1 Introduction

Chapter two concerned research on metacognitive skills and the research questions for this thesis. This chapter starts with a summary of how my research shifted from ontological and epistemological perspectives to pragmatism in section 3.2. In section 3.3, there is discussion of research methodology and data collection methods as well as the instruments chosen for my study. This is followed by an outline of ethical issues pertinent to my research and the last section 3.5 provides a short summary of the chapter.

3.2 From Ontological and epistemological assumptions to pragmatism

In the social sciences, ontology is concerned with what may be known about social phenomena and epistemology is concerned with ‘how we come to know what may be known’ about the social phenomena (Grix, 2002, pg. 3). Research questions are likely to influence the ontological choices and this is likely to influence methodological choices (Searle, 2009). Some believe that unless a researcher has ‘a clear conception of the nature of the phenomena’ he/she is investigating, it is unlikely that they will develop ‘the right methodology and the right theoretical apparatus for conducting the investigation’ (Searle, 2009, p.9).

Ontological positions can involve philosophical constructs such as ‘objectivism’ and ‘constructivism’. Objectivism supposes that social phenomena and all the meanings attached to them exist independently of all social actors, while constructivism on the other hand, supposes that social phenomena and its attendant meanings are constantly influenced and shaped by social actors (Grix, 2002). At the beginning of my

study I believed that my ontological position was partly objectivist, but when I was confronted with the difficulty to interpret findings after completing the second part of my research (Study 2), I had to reconsider whether I subscribed to an ontological position at all.

Epistemology is defined in the Oxford Dictionary as ‘the theory of knowledge, especially with regard to its methods, validity, and scope, and the distinction between justified belief and opinion’. In other words, epistemology is concerned with the appropriate ways of gathering of knowledge. Initially, the epistemological assumption considered for my study was positivist. This is because the studies I conducted involved questions about cause and effect (i.e. positivist), however questions that arose from inconclusive findings from Study 2 (see chapter 5) demanded a different epistemological assumption. I realised that the research questions determined the research methodology, so I decided to abandon my ontological and epistemological assumptions and took the route of pragmatism.

3. 2.1 Pragmatism as a research paradigm

3.2.1.1 The Nature of research Paradigms

The term paradigm has been defined differently by different researchers. In the context of educational research methodology, a paradigm is defined as:

‘a set of philosophical assumptions about the phenomena to be studied, about how they can be understood, and even about the proper purpose and product of research’ (Hammersley, 2012, p.2).

Willis (2007) suggests that a paradigm ‘is thus a comprehensive belief system, world view, or framework that guides research and practice in a field’ (p.8) while Burgess et

al. (2007) put it very briefly as ‘a set of beliefs that deal with ultimates and first principles’ (p.54). According to Husén:

“... a paradigm determines the criteria according to which one selects and defines problems for inquiry and how one approaches them theoretically and methodologically” (Husén, 1997, pp.16-17).

While there are several paradigms, Burgess et al. (2007) identify paradigms that obtain within the educational research context; positivism, interpretivism, post-positivism, postmodernism, constructivism and pragmatism (e.g. Morgan, 2013). Taylor and Medina (2013) argue that ‘no research paradigm is superior, but each has a specific purpose in providing a distinct means of producing unique knowledge’ (p.1). The choice of each research paradigm will depend on the question(s) the researcher needs to investigate.

Pragmatism is often considered to be a replacement for the old order that conceptualized social research along the lines of ontology, epistemology and methodology. Morgan argues that

‘rather than framing the study of social science research as commitments to an abstract set of philosophical beliefs, pragmatism concentrates on beliefs that are more directly connected to actions’ (Morgan, 2013, p.1051).

A pragmatic approach to research is not premised on a set of defined ontological, epistemological and methodological assumptions rather, it considers the nature of the question to be researched raising issues such as; what are the choices to be made about the research to be carried out? Why should these choices be made? And what is the impact of making this set of choices rather than the other? (Morgan, 2013).

Pragmatism is primarily concerned with placing more importance on the research question (Tashakkori & Teddlie, 2010). Johnson and Onwuegbuzie (2006) argue that pragmatism is more focused on the outcome of the research process and making meaning out of it. Pragmatism is viewed as advocating for ‘complementarity’ of research approaches, that is, qualitative and quantitative data collection methods can converge in a single research to complement each other’s strengths and deficiencies (Johnson and Onwuegbuzie, 2006). For this reason, pragmatism has been paired with mixed method approaches. In my research, when quantitative data was difficult to interpret in Study 2 (see Chapter 5), the next practical alternative was to design a study (Study 3) which would yield qualitative data and this combination was in essence a pragmatic approach to research involving making choices about what works rather than following philosophical claims.

3.3 Methodological Choices

Methodology is defined as

“the strategy, plan of action, process, or design lying behind the choice and use of particular methods and linking the choice and use of the methods to the desired outcomes” (Crotty, 2003, p. 3).

In other words, methodology is concerned with the broad process of designing the research strategies, and establishing a connection between choices of methods and their use and the results of the research required to answer specific question/s. Methodology is thus distinguished from methods employed to collect data during the research. In the following sections I first outline the reasons for using a quasi-experimental design, and then give details of the data collection methods.

3.3.1 Choice of quasi-experimental research design

Quasi-experimental research often involves an experimental and a control group, but where participants are not randomly assigned to treatment groups. However, the conditions of treatment should be similar except for the aspect being investigated (or the independent variable) (Shavelson and Towne, 2002). In my research, the design strongly leaned towards the experimental design, as the only major aspect missing from the design was the random allocation of participants to treatment groups. Research contexts that involve cause and effect relationships such as the effect of instructional interventions are most appropriately carried out using the experimental approach (Mayer, 2005).

From their study of inquiry methods in education, Shavelson and Towne (2002) concluded that due to their ability to facilitate balanced comparisons, randomised trials (RTs) are the most suitable to establish a causal relationship between dependent and independent variables. Mayer (2005) also concurs by observing that experimental methods which involve random assignment of participants to treatment and control conditions “have been the gold standard for educational psychology” since the field came into existence (p.74). Mayer argues that when carried out in the correct manner, they

“allow for drawing causal conclusions, such as the conclusion that a particular instructional method causes better learning outcomes” (p.75).

In conclusion the experimental research method has often been viewed as a suitable research method to employ when investigating the effectiveness of an instructional intervention and hence this is why I chose the quasi-experimental method for my study.

While the experimental research method is considered by some to be the best method for finding out the casual relationship in instructional interventions, it is not without limitations. It is argued that random allocation of participants and the existence of a control group could impose an artificial outlook on the research context, and may also disadvantage some students. Perfect and well controlled experimental conditions usually are not possible to achieve in authentic and dynamic learning environments such as those found in schools. This means that a compromise might be required between a strictly experimental set up with tight controls and what can be practically found in an authentic classroom environment. For example, my study reported in Chapter 4 involved two different teachers, each teaching a different group of participating students (control and experimental). This introduces an inevitable variation to the authenticity of the collected data.

3.3.2. Data collection Methods

Methods refer to techniques or procedures that are used to collect data required to address a research question (Crotty, 2003). The methods used to collect data in this study included questionnaires to assesses metacognitive skills, stoichiometry problems to assess learning, group interviews with students and semi-structured interviews with teachers. The sections below discuss the reasons for choosing these methods of data collection.

3.3.2.1Metacognitive Awareness Inventory (MCAI)

This subsection concerns a metacognitive awareness survey instrument (MCAI) as a data gathering tool. I highlight the advantages and disadvantages of using this self-report questionnaire measure. The MCAI (Appendix 3) was specifically developed to 'assess students' metacognitive skilfulness during problem-solving in chemistry' (Sandi-Urena and Cooper, 2009, p.240). It consists of 27 items on a 5-point Likert

survey scale where 1= NEVER and 5= ALWAYS. This instrument was chosen for my first and second study because it is specifically designed to self-assess metacognitive skills in students during problem-solving in chemistry.

My research was concerned with assessing gains in metacognitive skills awareness resulting from metacognitive instructional interventions during problem-solving in stoichiometry. For this reason, MCAI was a particularly suitable tool to use; although there are other metacognitive assessment tools such as Metacognitive Awareness Inventory (MAI) (Schraw and Dennison, 1994) and Assessment of Cognitive Monitoring Effectiveness (ACME) (Osborne, 1998) however, these appear to assess general metacognition (Thomas et al., 2008).

The MCAI is a convenient way of collecting data quickly and efficiently (Sandi-Urena and Cooper, 2009). Self-report measures such as MAI and MCAI enable researchers to analyse relationships between metacognitive skills and specific academic skills such as scores of achievement tests (Young and Fry, 2008). Young and Fry using a similar assessment tool the metacognitive skills awareness inventory (MAI) found a significantly positive correlation between college students' metacognitive awareness and their academic achievement.

The MCAI has structured statements which allow participants to reflect on their responses and these responses are likely to be a function of their learning experiences in the previous lessons and as result this could reduce or eliminate the possibility of replicating responses from the pre-test in the post-test (Young and Fry, 2008). The instrument was designed and validated for use at tertiary level (Sandi-Urena and Cooper, 2009). Even so, the statements are easily understandable and are accessible by secondary school students. The study by Sandi-Urena and Cooper to validate the MCAI involved undergraduate general chemistry students, with 290 participants at

pre-test ($N=280$, $M=75$) and 280 participants ($N=280$, $M=73.4$) at post-test. There was also a replication study carried out involving 609 participants ($N=609$, $M=76$) at pre-test and 605 at post-test ($N=609$, $M=75.2$). In both cases, an analysis of MCAI scores by grade levels indicated a correlation between mean MCAI scores and achievement, i.e. high achieving participants had high MCAI means scores; A grade participants had MCAI means score of 77.3, B grade had 74.1, C grade had 73.3 and D grade had 71.8. The MCAI scores for A grade students were significantly different compared to the MCAI mean scores of students with other grades. The reliability of the instrument was measured in terms of internal consistency using Cronbach's α and values ≥ 0.85 were obtained. Alpha values above 0.70 indicate that the results of the instrument have internal consistency and can be reproduced (Sandi and Cooper, 2009; Tavor and Dennick, 2011).

It is argued that the MCAI generates only one factor, yet metacognitive skills are analysed into planning, monitoring, control and evaluation (Sandi-Urena and Cooper, 2009). This suggests that this self-report questionnaire could fail to capture students' real use of metacognitive skills (Delvecchio, 2011). An argument against using self-report data by itself to measure metacognitive skills has been the absence of research which validates the students' questionnaire responses using a multi-method approach (Thomas et al., 2008; Sandi-Urena et al., 2011).

A further issue with MCAI is the interpretation of scores. For single use of the MCAI, a higher score on the MCAI is usually assumed to reflect higher levels of metacognitive awareness. However, previous researchers (Sandi-Urena et al., 2011) have reported that a decline in MCAI scores between pre-test and post-test as indicative of an increase in metacognitive awareness as well. While a decrease in MCAI scores could be viewed as a decline in metacognitive skills awareness, this alternative interpretation is supported by the argument that MCAI is a 'habitual behaviour self-

report and not an attitude inventory' (Sandi-Urena et al., 2011, p.333). In other words, MCAI assesses the participant's habitual use of the construct and not necessarily the participant's perception of the importance of it. The authors further suggest that as the participants increase their metacognitive awareness, so does their perception of the importance they attach to the construct and consequently they become stricter in their self-assessment resulting in the lowering of MCAI scores between pre-test and post-test. In spite of these limitations, the MCAI remained the best available instrument suitable for my studies.

3.3.2.2 Problem-solving Tasks in Stoichiometry (PSTs)

To assess whether the students had made progress in their ability to solve stoichiometry problems, I designed a Problem-Solving Task (PSTs, see Appendix 6) that was similar to standard examination questions set by the University of Cambridge Overseas International General Certificate of Secondary Education (IGCSE). The assessment of PSTs was completed using a mark scheme. As these were all well-defined problems (Appendix 9) there was little risk of bias or subjective assessment. These PSTs were well aligned to the students' chemistry syllabus on stoichiometry; therefore they were designed to be a valid assessment of the students' abilities in stoichiometry and any pre- to post-test improvements.

3.3.2.3 Group interviews

This section introduces, describes and discusses a group interview as a technique for gathering qualitative data. The reasons for choosing this technique for the study in Chapter 6 and its strengths and limitations are discussed. A group interview is a technique used to collect qualitative data and often it involves the use of in-depth discussions when selected participants do not necessarily represent a particular sampling of a given population but have a purposeful topic to explore (Thomas et al.,

1995). There have been criticisms of this method. Some researchers suggest that participants should not be familiar with each other in order to facilitate genuine responses and a spontaneous expression of a wider range of personal views on issues under discussion (Rabiee, 1999). It also has been argued that the absence of familiarity among participants helps to prevent behaviours emanating from pre-existing relationships and certain patterns of leadership within the group (Thomas et al., 1995).

A different point of view has also been put forward, suggesting that participants are selected based on the following criteria; that they have sufficient knowledge within their age-range to make a meaningful contribution to the topic to be discussed; that they possess comparable socio-characteristics and that they would experience no discomfort in interacting with each other and the interviewer (Richardson and Rabiee, 2001; Burrows and Kendall, 1997).

It has also been suggested that it is desirable that members of the group feel comfortable in each other's company and be able to freely engage in discussion without feeling constrained. Krueger (1994) argues that in order to obtain rich data, members of the group must be disposed to participate fully in the discussion and consequently he suggests the use of a homogeneous group. Krueger (1994) also advocates that participants share common characteristics such as gender, age-group, ethnicity and social-class. Kitzinger (1994) also supports using pre-existing groups, arguing that familiar colleagues could relate positively to each other's responses and may feel more comfortable challenging or enhancing each other's contributions.

It also has been noted that group interviews can produce data that is difficult to analyse, and the researcher has less control over the data generated (Morgan, 1996; Krueger, 1994). In addition, the method demands carefully trained interviewers, and

the discussion should be carried out within an atmosphere that promotes dialoguing (Morgan, 1996; Krueger, 1994).

In this study, semi-structured group interview methodology was chosen in order to find and understand a possible explanation to participating students' beliefs and perceptions about their use of metacognitive skills during problem-solving tasks in stoichiometry. Although students had completed the metacognitive awareness inventory (MCAI) self-report where they reported their metacognitive awareness and the use of metacognitive skills, there was no opportunity for them to express their views, beliefs or perceptions on how they use metacognitive skills during problem-solving tasks (PSTs). Group interviews provided them with an opportunity not only to express their views, but also to provide explanations on beliefs, perceptions and attitudes towards solving stoichiometric problems. One-to-one interviews were not considered suitable as the focus of the study was not to get an in-depth understanding of individual views and also, the topic of discussion was considered to be dealing with habit-driven issues (Morgan, 1996).

The choice of semi-structured questions was based on the nature of the phenomenon to be investigated. Metacognitive processes are invisible and do not involve verbal or non-verbal behaviour (Efklides, 2005). Semi-structured interviews allow qualitative data to be collected by way of getting participants to state how they structure their thinking during problem-solving. Semi-structured interviews will allow students to make guided elaboration on their responses, something they cannot do if structured interviews or questionnaires were to be used. Qualitative data gathered from semi-structured interviews allows the study to build a complete picture of both cognitive and affective experiences gained by the participants during the study, something that quantitative methods alone may not capture.

3.3.2.4. Semi-structured Interviews

This section describes and discusses the research method used to collect data which is reported in Chapter 7. Interviews used for data collection techniques in qualitative research can be described as a process that involves

“conducting intensive individual interviews with a small number of respondents to explore their perspectives on a particular idea, program or situation” (Boyce and Neale, 2006, p.3).

In general, interviews are more powerful than questionnaires in generating narrative data that allows researchers to uncover informants' perceptions, views and ideas in greater detail (Kvale, 2003). Interviews also permit participant informants to share their own views, beliefs, thoughts and sentiments and 'speak in their own voice' (Berg, 2007, p.96). There are three types of interview techniques; structured, semi-structured and unstructured. Structured interviews involve the use of questions which are prepared beforehand which are presented in the same order and sequence to each interviewee. Unlike structured interviews, unstructured interviews do not involve the use of pre-written questions. The interview often makes use of open ended questions which can be asked in no particular order. Semi-structured interviews stand between structured and unstructured interviews. It is a data gathering technique that combines the benefits of prearranged questions with the flexibility to follow up on issues that could be of relevance. The focus of the interview is determined by the researcher and the depth of the conversation depends on researcher's interviewing skills.

It is useful to outline the reasons for my choice of semi-structured interviews with the teachers of the experimental and control groups to collect data about awareness of metacognitive instructional methods. This investigation required gaining an insight

into the teachers' approaches in teaching stoichiometry. This could not be achieved by using questionnaires because it was important to get reasons for teachers' choice of teaching approaches; and questionnaires are mostly limited to 'yes' and 'no' type of responses or ratings. This would have limited what the interviewer and interviewee could say (Berg, 2007). In addition, semi-structured interview was chosen because the second aim of the study was to understand whether teachers used metacognitive approaches in their teaching. Metacognitive processes are not obvious and require verbalization by the respondent, something that can only happen in an elaborate conversation (Efklides, 2005).

Since semi-structured interviews often involve open-ended questions; it was anticipated that teachers would be able to elaborate on themes under discussion in more detail and follow up questions could be asked in order clarify any unclear statements or ideas. This was seen as an advantage that would confer high validity to the data collected. Semi-structured interviews are easy to record, although the data collected may sometimes be difficult to analyse (Berg, 2007; Kvale, 2003).

While interviews have been criticised for being time-consuming with respect to data collection and the subsequent analysis (Berg, 2007) I did not see this as a limitation, but just a necessary inconvenience. Although interviews take lot of time to conduct, I collected data by audio recording. My study required just one hour of audio recording and nearly three hours of transcribing.

3. 4 Ethical considerations

The investigations were guided by national guidelines about ethical research (BERA, 2011; Research council of Zimbabwe, 2014). The research was granted ethical approval by the Open University Human Research Ethics Committee (HREC, on 12 March 2015 and April 2016). Relevant documents about ethics are referred to in the subsequent chapters, and have been placed in Appendices (10-15). What follows is an outline of some of the major issues that were addressed.

The students chosen for this study were given a full briefing about the nature and the purpose of the study and they were not chosen on the basis of gender, race, ethnicity, nationality, cultural identity, faith, disability, or any other significant differences (BERA, 2011; Research council of Zimbabwe, 2014). Students participated in the study on the basis of voluntary informed consent and parental consent was sought. It was pointed out to the students that they might acquire skills during the study which benefitted their problem-solving skills in stoichiometry. A preview of the activities that the chosen participating students engaged in during the study was given to all students in order to help them understand what the study would involve. This outline was also designed to inform students who may have been prejudiced against research activities holding the belief that all individuals who take part in such activities are 'guinea pigs'. Students were made aware that the study may involve the use of audio recordings to capture their contribution during interviews. They were advised that only the researcher would make use of that information solely for the purpose of the research.

It was made clear to the students that they had the right not to participate in the study and could withdraw at any time during the first week of the study and any data collected would not be used for analyses. However, if they chose to withdraw after a week, any data collected would be included for analyses. In the event that a student

chose to withdraw, reference was made (without appearing to coerce) to the potential loss of an important skills development opportunity.

The students were advised that findings from the study would be shared with them on an individual basis if they wished to know about these, but no reference to individual or group of participants was to be made. Third party consent was not required on the part of the participants as they were sixteen years of age or above (Zimbabwe Research Council, 2014). Despite this, consent was obtained from the students and their parents. The researcher was already in compliance with the legal requirements (clearance from relevant authorities to enter and conduct research in schools) stipulated for people who work with school children or vulnerable young people. The researcher was therefore legally qualified to work with the young people in this study within the environment in which the study is to be conducted.

The participants were advised of the confidentiality and anonymity with which their data would be treated. They were told that no part of the research report would disclose any individuals by name or otherwise. The participants were made aware that their data would be kept in compliance with the Data Protection Act (Zimbabwe) and no third part will have access to it, but should circumstances arise that may necessitate disclosure of their data to third parties, a written consent would be sought from them. Participants were advised that if the findings were published, no individual names or the name of the school would be mentioned in the study without their consent. They were told that pseudonyms would be assigned to protect their identity. All information would be held securely and no name would be entered in any computer records.

The research was carried out in normal science classrooms. The participants were not randomly assigned to one of three groups as all three groups were located in different

campuses. One group was given extra tuition in chemistry which was similar to the usual classroom teaching; the other group(s) were be given similar teaching with advice about planning, monitoring, control and evaluation. Participants were told that when they agreed to take part in the study they could not be sure which group would learn more about stoichiometry. The name and contact details of the main supervisor of the project and the Director of the Post graduate studies (CREET) were available to participants in case they had queries concerning the study.

3.5 Chapter Summary

In this chapter I have addressed issues relating to how my research evolved from taking ontological and epistemological perspectives to research, to a pragmatic approach. The decisions about these issues were informed by the nature of my research questions and the phenomenon to be researched. It was argued that a pragmatic approach to research is not premised on ontological, epistemological and methodological assumptions, rather, it considers the nature of the question to be researched raising questions such as; what are the choices to be made about the research to be carried out? Why should these choices be made? And what is the impact of making this set of choices rather than the other? (Morgan, 2013).

On methodological assumptions, methodology was distinguished from methods employed to collect data during the research. The methodology used for Study 1 and 2 was quasi-experimentation involving pre-test and post-test analysis and data was collected using questionnaires and performance on stoichiometric problems. The reasons for choosing MCAI as a tool for assessing MS were discussed including its limitations. Group interviews were used for Study 3 while semi-structured interviews where used for Study 4. Reasons for the choice of methods for data collection were discussed in detail.

The remaining part of the thesis contains four chapters which present research findings. Chapter 4 concerns a study on the effect of an instructional intervention (MSF) on the students' achievement in stoichiometry and metacognitive skills awareness and use. Chapter 5 contains a further study which compares the effectiveness of two metacognitive instructional interventions; metacognitive skills framework (MSF) and metacognitive skills modelling (MSM) on improving students' achievement in stoichiometry and metacognitive skills awareness and use. Following inconclusive findings from Study 2 reported in Chapter 5, a further Study 3 reported in Chapter 6 was carried out and was concerned with the students' group interviews while study 4 which involved teachers' interviews is reported in Chapter 7. The thesis concludes with Chapter 8, the discussion chapter.

Chapter 4: Study 1: The effect of instructional intervention on students' metacognitive skills and achievement during problem-solving in IGCSE stoichiometry.

This investigation concerns the impact of an explicit instructional method called metacognitive skills framework (MSF) on students' metacognitive skills awareness and abilities to solve stoichiometric problems. The introduction provides a summary review of studies that have been carried out on metacognition within science education at tertiary and secondary school level as reported in Chapter 2 of this thesis, and considers instructional methods that could help develop metacognition and methods to evaluate these developments.

The review emphasises that direct and explicit metacognitive instruction can help students to improve their metacognition as well as increase their achievement gains. However, most of the studies reviewed here did not assess students' change in metacognition; therefore we cannot be sure about the extent to which the increase in the students' achievement corresponded to the increase in their metacognition. Section 4.1.1 reviews MSF as an explicit metacognitive instructional method. It provides a brief history of its development and how it was designed and used previously. Section 4.1.2 describes MCAI as an assessment tool for students' metacognitive skills and PSTs as an assessment tool for students' achievement in stoichiometry.

4.1 Introduction: Summary review of research on metacognitive instructional methods

In Chapter 2 it was reported that there has been an increase in interest in studying metacognition in science education over the last three decades, particularly in the area of instructional methods that enhance metacognitive knowledge and

metacognitive skills (Georghiades, 2004a; Blank and Hewson, 2000). This includes instructional methods that are specific to chemistry (Schraw et al., 2005; Tsai, 2001; Rickey and Stacey, 2000). It was also observed that the growth in the number of studies focusing on teaching metacognitive skills could be attributed to claims that metacognitive skills facilitate the achievement of a rich and profound understanding of ideas and concepts within specific subject domains (Yore and Treagust, 2006). This is believed to enable the student to move from being a dependent learner to being a self-regulated learner (Schraw et al., 2006). Again, as discussed in Chapter 2, researchers have reported that teaching metacognitive skills and metacognitive knowledge can increase students' achievement in learning irrespective of their learning abilities; and students who exhibited high levels of metacognition were found to outperform those with lower levels of metacognition (Swanson, 1990).

Results from studies have demonstrated that metacognition can be taught (e.g. Zepeda et al., 2015; Cook et al., 2013; Sandi-Urena et al., 2011; Pennequin et al., 2010; Schraw et al., 2005; Rickey and Stacey, 2000). As reported in Chapter 2, Pennequin et al., (2010) investigated if metacognition training involving the use of Schraw's (1998) direct and explicit instructional method known as Strategy Evaluation Matrix (SEM) could enhance metacognitive knowledge and metacognitive skills and the mathematical problem-solving capabilities of typical children.

Findings showed that those children who were in the experimental group showed higher post-test metacognitive knowledge, metacognitive skills and problem-solving abilities compared to those in the control group. In addition, the results also indicated that the lower ability students benefited from metacognition training as they were able to make significant progress, and were able to accurately complete the same number of problems on the post-test, as the more able students in the pre-test.

However, the study did not assess the students' metacognition, so we cannot be sure whether their metacognition did or did not improve.

Zepeda et al., (2015) investigated whether a six-hour intervention that was designed to teach metacognitive skills components; planning, monitoring and evaluation could increase students' metacognition, motivation and other learning skills required for future learning in middle school science. The study involved forty-six eighth grade students who were randomly assigned to either a control or experimental group. The control group received intensive problem-solving practice in physics, while the experimental group received limited problem-solving practice but was given metacognitive instruction and training.

The results showed that the experimental group improved their problem-solving abilities and performed better on conceptual physics. The researchers concluded that metacognitive instruction 'can lead to better self-regulated outcomes in adolescent students' (Zepeda et al., 2015, p.1). This study involved the use of direct and explicit metacognitive instruction. But again, there was no assessment of metacognition, so we cannot be sure whether the difference in achievement between the experimental and the control group could be purely attributed to metacognitive instruction and training.

In another comparable study (also reported in Chapter 2) Cook et al. (2013) in their study involving 700 first-year college students majoring in science, investigated the impact on performance of teaching metacognitive strategies in chemistry. The metacognitive instruction involved the use of the Blooms' Taxonomy (described in Chapter 2) to teach metacognitive skills. Results indicated that those students who received training on the use of metacognitive strategies improved their performance in their first examination by a whole grade suggesting that there is a connection

between gains in metacognition and learning achievement. Again this indicates that direct and explicit metacognitive instruction helps students to make gains in achievement as a result of improved metacognition. However, there was no assessment of metacognitive skills to show how these had improved during the training.

In another study, Sandi-Urena et al., (2011; see also Chapter 2) investigated the effectiveness of intervention involving collaboration to promote college general chemistry students' metacognitive skills awareness and use. The study involved a quasi-experimental control and experimental design with 1001 participants. The MCAI was used to assess the participants' metacognitive skills awareness and use. The experimental group, compared to the control group, showed a significant increase in metacognitive skills awareness as shown by the MCAI scores.

Finally, in a study involving the use of metacognitive framework, Delvecchio (2011; see also Chapter 2) investigated how this explicit metacognitive instructional method affected High School students' use of MS and their problem-solving abilities in challenging chemistry problems. The study involved the use of MCAI self-report measures and problem-solving tasks (PSTs) in a quasi-experimental design involving pre- and post-test measures.

The study involved 39 participants and results showed no significant improvement in metacognition for the experimental group while the same group made significant gains in chemistry achievement compared to the control group. This study showed that a metacognitive instructional method can help students increase their achievement in chemistry, but it had little impact on their metacognitive skills. The study did investigate the correlation between metacognitive skills (MCAI scores) and achievement in chemistry (PSTs scores) found significant correlation.

The studies described above have indicated that teaching metacognitive skills helps students to increase achievement gains. However, most studies (apart from Sandi-Urena et al., 2011 and Delvecchio, 2011) have not reported the assessment of gains in metacognitive skills by students and it's only by making assumptions that increase in students' achievement gains is a result of improved metacognition. Thus, there is a need for studies where gains in achievement are assessed along with improvement in metacognitive skills in order to establish a link between the two. In addition, the instructional methods employed in the studies above, apart from Delvecchio (2011) did not target specifically the components of metacognitive skills and it is for this reason that I decided to investigate the effectiveness of MSF in enhancing the students' metacognitive skills and achievement in stoichiometry and assess these in order to establish whether a correlation exists.

4.1.1 Using the Metacognitive Skills Framework as an Instructional Method

Explicit instructional methods using clear and unambiguous teaching are believed to be effective in enhancing metacognitive learning (Ellis et al., 2014). This teaching approach involves the use of a sequence of supports or scaffolds where:

'students are guided through the learning process with clear statements about the purpose and rationale for learning the new skill, clear explanations and demonstrations of the instructional target, and supported practice with feedback until independent mastery has been achieved' (Archer and Hughes, 2011, p. 1).

As reported in Chapter 2, one explicit instructional method that has been developed is called the metacognitive skills framework (MSF) which was initially used to teach problem-solving in stoichiometry to high school students (Delvecchio, 2011). Delvecchio called it the metacognitive framework. Around this time Whitebread et al.,

(2009) developed the Cambridgeshire Independent Learning (C.Ind.Le) which was designed to study metacognitive skills in young children and was not used as an instructional tool, rather it was used to observe metacognitive skills in young children. However, this observational tool identified examples of the four components of metacognitive skills and had the potential to provide a template of the types of metacognitive skills that could be taught to students. I adapted the C.Ind.Le., using some of Delvecchio's ideas to produce a teaching tool which included planning, monitoring, control and evaluation which I decided to call the metacognitive skills framework (MSF) because it teaches metacognitive skills or strategies. In addition, MSF differs from Delvecchio's metacognitive framework in that it contains another MS component; control as suggested by Whitebread et al., (2009).

This teaching method consists of a template (see Appendix 1) outlining metacognitive skills components. As described in Chapter 2, each component carries a set of strategies that students use to focus their effort during problem-solving. For example, for the planning component students were advised to read the whole question before attempting to solve the problem, isolate relevant data, think of a method or formula to use, etc. Similar instructions are given for all other components i.e. monitoring, control and evaluation.

Although Delvecchio (2011) evaluated the effectiveness of the metacognitive framework, there was no control group and the participants were pre-university students, while participants in this study were middle high school students. However, the most important difference is that in Delvecchio's study, there were other instructional methods used; think-aloud pair problem-solving protocols and two design labs. This would make it difficult to be sure of the MSF's contribution to the outcomes of the investigation.

4.1.2. Assessing metacognitive skills awareness and achievement in stoichiometry

4.1.2.1 Metacognitive Awareness Inventory (MCAI)

To assess students' metacognitive awareness and reported use, an assessment instrument called Metacognitive Activities Inventory (MCAI) was used (Chapter 3 and Appendix 3). The MCAI was designed by Sandi-Urena and Cooper (2009) to specifically assess students' metacognitive skills during problem-solving in chemistry. The authors of this assessment claim that it offers instructors a tool that enables them to gain a deeper understanding of students' perception of how they solve chemistry problems. The MCAI was also chosen because it appears to provide a reliable assessment of metacognitive awareness of students (Young and Fry, 2008) and provides data about the four components of metacognitive skills.

The MCAI is a convenient way of collecting data quickly and efficiently. It can be used to collect data from large samples at minimum cost of researcher and teacher time. It has structured statements which allow participants to reflect on their responses and these responses are likely to be a function of participants' learning experiences in the previous lessons and this reduces the possibility of replicating responses from the pre-test in the post-test (Young and Fry, 2008). The MCAI is described as 'a robust, reliable, and validated assessment of metacognition use in chemistry problem-solving' (Sandi-Urena and Cooper, 2009, p.244).

Self-report assessment tools such as the MCAI are not without their drawbacks. Self-report surveys are generally biased by the feelings of the respondent who may overstate or understate their responses at the time of completing the report. For example, if the respondent is feeling good they are likely to respond more positively than if they were having a bad day. Sandi-Urena and Cooper (2009) claim that MCAI is

designed to detect students who overstate their metacognitive awareness by comparing their self-report scores against their actual performance in metacognitive tasks. This assumes the existence of a correlation between metacognitive skilfulness and achievement gains.

A further claim by the authors is that this assessment tool can be 'used by practitioners to evaluate the effect that changes in their teaching practices or learning environments may have on the use of metacognitive skilfulness by their pupils' (p.244). The instrument can also be used to assess the effectiveness of metacognitive instructional interventions (Sandi-Urena and Cooper, 2009). A potential limitation of the MCAI is that it was designed and validated for students at tertiary level and may not necessarily be suitable for use among secondary school students. It also contains eight negatively worded statements and according to Schmitt and Stuits (1985), respondents generally find it difficult to accurately interpret such statements.

Although there are supportive claims about the validity of the MCAI there are issues about its interpretation. A higher score on the MCAI is obtained when students give answers which reflect higher levels of metacognitive awareness. However, in previous research, when the MCAI has been used as a pre-test and post-test assessment tool, there was a reduction in MCAI scores when students rate their own metacognitive awareness at post-test. This would suggest that the students' metacognition has become worse. However, an alternative interpretation has been put forward that the training results in greater self-awareness of metacognition so that the students realise at post-test, and unlike at pre-test, that they are not always engaging in metacognition so that self-ratings of metacognition are reduced (Sandi-Urena and Cooper, 2011).

4.1.2.2. Problem-solving Tasks (PSTs)

PSTs as described in chapter two are defined stoichiometry problem tasks which are based on standard University of Cambridge past examination questions. I could not use the PSTs used in Delvecchio's study because her study involved 'A' level students and this study involved GCSE students as previously stated. In addition, past research has not identified suitable stoichiometry PSTs at secondary school level which can be used in studies similar to this study and therefore I decided to devise one based on my experience of past exam papers. The PSTs had definitive solutions as they were numerical, therefore the issue of bias on assessment was unlikely to arise.

4.1.3 Summary

To summarise, there is evidence from previous research that metacognition can be taught through classroom instruction. Explicit instructional methods have been identified as enhancing the development of metacognitive skills (Ellis et al., 2014). In addition, there is also evidence from research that there is a connection between metacognitive awareness and learning achievement. This study was concerned with the impact of metacognitive skills framework as an explicit metacognitive instructional method on students' metacognitive skills awareness and use during problem-solving in stoichiometry. The study addressed the following questions:

1. Does using an explicit metacognitive skills instructional method (MSF) to teach problem-solving in stoichiometry improve students' metacognitive skills awareness?
2. Does the use of an explicit instruction method (MSF) raise the attainment of the students?
3. Is there a relationship between students' achievement in stoichiometry problem tasks (PSTs) and metacognitive awareness?

4.2 Method

4.2.2 Participants

The participants were high school students studying chemistry at a school in Harare, Zimbabwe. This school was chosen because it is a specialist school of science. All students followed the University of Cambridge IGCSE chemistry curriculum and they were on the course by choice. A total of 41 students took part in this study. The sample included 18 girls and 23 boys. The experimental group consisted of 9 girls and 12 boys and the control group consisted of 9 girls and 11 boys. The two groups of students were located at different campuses so that Group A (experimental) and Group B (control) were randomly allocated to the experimental and control conditions. It was not possible to randomly allocate individual students to the groups because the two groups were located in two different campuses of the school which made it impractical to randomly allocate participants. Ethical approval for the investigation was given by the Open University (see Chapter 3). Consent was sought and obtained from the school head teacher (Appendix 15), the participating teacher (Appendix 13), participants and their guardians (Appendix 10).

4.2.3 Measures

The students' baseline metacognitive skills were assessed prior to the intervention using the MCAI (Sandi-Urena and Cooper, 2009: see Appendix 3). The inventory consists of 27 items and uses a 5-point Likert scale that ranges from 1-strongly disagree to 5-strongly agree. The students' scores were expressed as a percentage of the total points ($27 \times 5 = 135$) and a mean percentage score was calculated for both control and experimental group.

The chemistry problems were derived from standard Cambridge IGCSE exam type questions as previously stated. The pre-test (Appendix 6) and post-test (Appendix 8) problems were similar in structure and level of exigency. One problem set was administered for pre-test and another for the post-test. The maximum score for the problems was 20 points which were converted into percentage points. The researcher marked both pre-test and post-test problems. This was done following the standard Cambridge IGCSE exam mark scheme. The marking followed marks schemes provided by the Cambridge Examinations board.

4.2.4 Procedure

To investigate metacognitive skills, two pre-tests, one in the form of metacognitive activity inventory (MCAI), and another in the form of a chemistry problem, were administered to both groups during the first lesson of the intervention. The students were given the MCAI first and immediately after completion they were given the stoichiometry problem task. This was followed by three weeks of intervention during which, each group was taught stoichiometry twice a week for thirty-five minutes. To minimise disruption of normal lessons, the students were taught after school hours during their extra-lessons slot. A post-test was administered during a final extra lesson. Both pre-test and post-test were administered by the teacher of each group.

4.2.5 Intervention

During the intervention students in Group A were taught using the metacognitive skills framework while the control group was taught using traditional non-metacognitive methods (teaching as normal). Students in the control group were taught the same subject matter on stoichiometry by a different teacher to the one who taught the experimental group. The teachers aimed to complete one stoichiometry problem task in every lesson. Each lesson involved a different problem task (Appendix 9).

Teaching using the MSF required the teacher to demonstrate how to use the content of the framework. The teacher was instructed by the researcher on how to use the MSF by demonstrating the content of the framework. For example, the teacher was instructed to demonstrate the planning phase by reading the problem task (step 1) with the students and then identify relevant information (step 2) followed by identifying the goal of task (step 3) breaking down the problem in small chunks if necessary (step 4). This was repeated for the monitoring, control and evaluation phases. Students were then given practice problem tasks to solve following this work with the MSF.

The teacher was instructed to encourage the students to make use of the framework to avoid the temptation of students resorting to their usual way of solving stoichiometry problems. The students in the control group were taught the usual way i.e. the non-metacognitive way. The teacher of the control of group was instructed to teach the students using his normal teaching approach. Discussion with the teacher revealed that he was not aware of metacognitive strategies and was therefore unlikely to employ them or use them to any extent during the intervention.

4.3 Results

The results table below shows a decline in the MCAI scores for the treatment group suggesting an increased use of metacognitive strategies during the intervention while for the control group there was almost no change.

Table 4.1: MCAI mean percentage scores, standard deviations, skewness and kurtosis of the experimental and control groups

Group	Measure	<i>N</i>	<i>M</i>	<i>SD</i>	Min	Max	Skewness	Kurtosis
Experimental	Pre-test MCAI	19	66.65	9.90	51.11	86.66	0.53	-0.41
	Post-test MCAI	19	60.47	12.50	34.70	85.18	-0.81	-0.58
Control	Pre-test MCAI	21	69.01	7.10	54.80	80.70	-0.28	-0.43
	Post-test MCAI	21	69.92	7.40	55.30	84.20	-0.84	-0.26

As parametric statistics are based on the assumption of normality of data distribution, it was necessary to evaluate the normality of the data scores before applying a parametric statistical analysis. The values of skewness and kurtosis fall within the acceptable z-score ($\alpha=0.05$) limits of ± 1.96 ($N < 50$) (West et al., 1996). This suggests that the data scores generally followed a normal distribution allowing for the application of parametric statistical tests.

A two-way 2 (time) x 2 (groups) repeated measures ANOVA was run on the MCAI scores to examine the effect of Group and Time. The analyses showed that there was no main effect of time; $F(2,37)=2.90$, $p=0.097$, $\eta p^2= 0.073$, indicating that there was no significant overall improvement of students' metacognitive awareness and use over the period of the intervention. The analyses showed that there was a main effect of group; $F(2,37)= 7.18$, $p=0.011$, $\eta p^2= 0.163$ indicating that there were significant group differences in the MCAI scores over time. There was no significant interaction, indicating that effects did not vary across time and group during the course of the intervention; $F(2,37)=1.59$, $p=0.216$, $\eta p^2= 0.041$.

A one-way ANOVA test revealed statistically significant differences between the two groups MCAI scores at pre-test and post-test; pre-test $F(2,37)=6.9$, $p=0.012$ and post-

test $F(2,37)=1.38$, $p=0.238$. This suggests that the main effect of group was mainly due to the difference in the pre-test MCAI scores.

Table 4. 2: Mean PSTs percentage scores, standard deviation, skewness and kurtosis from the chemistry questions for the control and experimental groups

Group	Measure	<i>N</i>	<i>M</i>	<i>SD</i>	Min	Max	Skewness	Kurtosis
Experimental	Pre-test PST	19	60.31	28.9	20.00	100.00	-0.13	1.45
	Post-test PST	19	87.74	14.0	55.00	100.00	-2.06	0.44
Control	Pre-test PST	21	44.52	20.0	15.00	85.00	0.58	-0.97
	Post-test PST	21	50.71	18.3	20.00	90.00	0.50	-0.56

The mean pre-test and post-test scores of chemistry problem-solving for Group A was higher than that of the control group, suggesting that the experimental group was more able at solving chemistry problems before and after the intervention. In addition, the results show that there was only a small difference between pre and post-test mean scores for the control group. In contrast, for Group A there was an increase in scores from the pre- to the post-test, indicating an improvement in chemistry problem-solving.

Another 2 x 2 ANOVA was carried out on the PST scores of the two groups. The analyses showed that there was a main effect of time indicating that there was a significant improvement of PST scores over the period of the intervention; $F(2,37)=23.1$, $p<0.001$, $\eta p^2=0.384$. There was also a main effect of group showing that there were group differences in PST scores; $F(2,37)=19.72$, $p<0.001$, $\eta p^2=0.348$ and a significant interaction showing that these effects varied across time and group; $F(2,37)=9.12$, $p=0.005$ $\eta p^2= 0.198$.

A one-way ANOVA test showed that there were differences between the post-test PST scores of the control and the intervention of group; $F(2,37)=47.42$, $p<0.001$. The analyses revealed no statistically significant differences between the pre-test PST scores of the two groups; $F(2,37)=3.49$, $p=0.07$.

The results suggest that there is a link between the metacognitive instructional approach and achievement in stoichiometry problem-solving. To investigate this possibility the change in the MCAI pre-test and post-test percentage scores for Group A (10.23%) and the control group (1.32%) were calculated. Similar calculations were carried out for the scores from the chemistry problems; Group A (45.90%) and the control group (13.90%). However, correlation calculations revealed weak non-significant Pearson correlations between MCAI scores and achievement scores; Group A ($r=0.166$) and the control group ($r=0.207$).

The correlation was computed using the Pearson correction. The Pearson correlation was chosen because it evaluates correlations between two continuous variables and it also determines the direction (-/+) and the extent to which the variables are correlated. Data distribution tests have shown that the data collected has a normal distribution, making the use of Pearson correlation in computing correlation suitable.

4.4 Discussion

This study investigated the impact of the MSF as an explicit metacognitive instructional method on the metacognitive skills awareness of students during problem-solving in stoichiometry. Results of the analyses indicate that the mean score of MCAI for the experimental group declined slightly from pre-test to post-test unlike that of the control group. This is consistent with findings from previous studies where students reporting higher metacognitive awareness at pre-test had lower post-test MCAI scores (Sandi-Urena et al., 2011).

The study also was designed to investigate whether there was an effect of the intervention on the students' chemistry achievement scores (PSTs). The analyses indicated that there was a significant improvement in the achievement scores of the experimental group, Group A, and no significant change in the scores of the control group. This is also consistent with previous findings from similar studies where students in the experimental group reported a significant improvement in their chemistry scores compared to the control group (Zepeda et al., 2015; Cook et al., 2013; Sandi-Urena et al., 2011; Delvecchio, 2011; Pennequin et al., 2010). These findings support the interpretation about the MCAI scores that the decline in MCAI scores from pre-test to post-test may have been a result of improved metacognitive awareness.

Together, these findings suggest that the slight decline in MCAI scores in Group A, may have been caused by a greater awareness of metacognitive processes at post-test as a result of MSF training. As a result, these students were more realistic in their rating of their metacognition in the post-test and were better able to solve chemistry stoichiometry problems (Sandi-Urena and Cooper, 2011). It therefore appears that the results reported here suggest the existence of a positive relation between metacognitive skills awareness and achievement scores.

4.4.1 The way the MSF could have increased students' achievement in stoichiometry

This section discusses how MSF as an explicit instructional method could have helped students improve on their metacognitive skills awareness and use. This is followed by a discussion of the link or relation between students' achievement scores and their metacognitive skills awareness.

The MSF as an instructional tool was targeted to develop the students' use of metacognitive skills during problem-solving in stoichiometry. The problem-solving efforts of group A students were focussed by following the different strategies set for each metacognitive skills component and this (in common with the results in the study by Sandi-Urena et al., 2011) appears to have led to the enhancement of the students' metacognitive skills awareness and use during problem-solving tasks.

The MSF template (Appendix 1) was not designed as an instruction tool (Whitebread et al., 2009). It is possible that the use of this template, in the current study allowed students to identify strategies linked to each metacognitive skills component as they progressed through their problem-solving tasks and this may have helped them to improve their metacognitive skills awareness and use. For example, strategies for the planning component suggested that the students should read the whole question, determine the goal, sort the information into relevant and irrelevant, break down the problem into small chunks, establish the relationship among any given data and decide on a strategy or method to find a solution. This deliberate and explicit guidance (Delvecchio, 2011) may have provided students with a clear focus during problem-solving tasks which appears to improve their metacognitive awareness and use.

The existence of a positive relation between gains in metacognitive skills and achievement scores in the problem-solving tasks is consistent with previous research (e.g. Cook et al., 2013; Sandi-Urena et al., 2011; Pennequin et al., 2010; Swanson, 1990). However, there was only a weak correlation between MCAI scores and PSTs achievement scores, this may be because what was important to increase PST scores was that there was some increase in metacognitive skills, but the extent of their use was less critical. As a result, MSF could have supported increases in metacognition that resulted in increased PST scores, but the extent of the increase in metacognitive

skills use did not relate to the PST gains made by the students. Previous researchers did not compute correlations between gains in achievement and MCAI scores; therefore, it is difficult to compare the present findings with findings from previous research in this regard.

4.5 Summary

In this study the effectiveness of an explicit instructional intervention method in changing students' metacognitive awareness and stoichiometry abilities was investigated. Results showed that for the experimental group there was no statistically significant difference between the students' pre-test and post-test mean MCAI scores suggesting that the students' metacognitive awareness might not have significantly changed over the time of the intervention. However, there was a statistically significant difference between the pre-test and post-test problem-solving tasks mean scores for the intervention group. This study, in common with similar previous studies, has supported the idea that metacognition can be taught and that there is a general link (though in the present study not statistically significant) between levels of metacognitive awareness and learning achievement.

Going forward, there is need to compare the MSF instructional intervention to other metacognitive instructional approaches and investigate the relative contribution of each component of the metacognitive skills to the students' overall metacognitive awareness and use. This will help teachers of stoichiometry to make informed choices when deciding on effective instructional interventions. The next study compares the effectiveness MSF and another explicit metacognitive instructional method in developing students' metacognitive skills awareness and use and considers the role of different components of metacognitive skills in the overall improvement of metacognitive skills awareness.

Chapter 5: Study 2: Comparing instructional effectiveness of MSF and MSM in developing students' metacognitive awareness and achievement during problem-solving in IGCSE stoichiometry.

5.1 Introduction

As discussed in Chapters 2 and 4, stoichiometry has been identified by science education researchers as one of the most challenging areas within chemistry, both at secondary school and undergraduate level. It was also noted that teaching metacognitive skills to students can help them improve their problem-solving skills (Schraw et al., 2006; Sandi-Urena et al., 2011; Rickey and Stacey, 2000). Effective problem-solving skills appear to depend on metacognitive skills and an instructional approach which promotes independent learning (Gunstone, 1999).

In the following literature review, two instructional interventions will be described, highlighting their differences and how each intervention is used in this investigation. The section is also concerned with the effectiveness of the two instructional methods as discussed in Chapter 2. There is a brief review of types of academic problems and the general approach taken by teachers of stoichiometry. The introduction ends with research questions addressed during the study.

5. 1.1 Metacognitive Skills Framework and Metacognitive Skills Modelling

Chapter 4 was concerned with the investigation of the effect of metacognitive skills framework (MSF) as an instructional intervention on students' metacognitive skills awareness and use. Results from Study 1 showed that there was no significant improvement in the intervention group's metacognitive awareness and use but there was a significant increase in achievement scores in chemistry, while the control group did not show any significant improvement. This study, Study 2, is concerned with

comparing MSF with another explicit instructional method which will be referred to as metacognitive skills modelling (MSM). Unlike MSF which involves the use of written template displaying strategies for implementing the four components of metacognitive skills as described in Chapter 4, MSM involves the teacher modelling these strategies during problem-solving. Metacognitive skills modelling during problem-solving requires the teacher to use think aloud protocols (TAPS) i.e. describing each step and giving reasons for each action carried out (Ellis et al., 2014).

In a comprehensive review of research on metacognition in science education spanning from 2000 to 2012, Zohar and Barzilai (2013) observed that there was a sharp rise in the number of studies involving metacognitive instruction and metacognitive training. The most frequently used instructional practice were metacognitive prompts, which were generally used in order to remind students to activate their MS during science learning. The prompts were usually metacognitive cues, questions or checklists (Zohar and Barzilai, 2013). Other frequently used instructional practices were reflective writing, practice and training; teacher led metacognitive discussion, and explicit instruction. The least used instructional practice was metacognitive skills modelling by the teacher (Zohar and Barzilai, 2013). However, there are indications that this technique may be effective (Ellis et al., 2014).

MSM involves the use of traditional and generic teaching strategies associated with explicit instructional approaches. MSM was chosen for this study because like MSF it is an explicit metacognitive instructional approach. It requires the teacher to model the use of metacognitive skills during solving stoichiometry problems. MSM differs from MSF in that it is not as explicit as MSF where students are given written strategies for implementing the four metacognitive skills components during problem-solving. Modelling metacognition can facilitate a dialogue in which scientific ideas and

concepts are explored and in turn this allows the students' understanding to be evaluated and also to judge whether the learning outcomes have been met (Davis, 2003). Thus, MSM was chosen to test whether the use of modelling with less explicit instructions would help students more or less than the MSF.

5.1.2 Well-defined and ill-defined problems

It has been suggested that problems can be grouped as algorithmic or conceptual (Cracolice et al., 2008). Algorithmic problems are referred to as well-defined problems which have known solutions, whereas conceptual problems are described as ill-defined problems which have no specific solutions (Cracolice et al., 2008). This difference suggests that metacognitive instructional methods required for each type should be different. The main issue with studies about instructional methods that are used in teaching metacognitive skills is that they often do not differentiate between instructional methods that are best suited for teaching ill-defined and well-defined problem-solving (Zohar and Barzilai, 2013). The MSF is well adapted to help students develop metacognitive skills strategies during stoichiometry problem-solving because the template contains all the strategies students should follow during problem-solving. The MSM gives the teacher an opportunity not only to demonstrate, but also to explain the importance of the metacognitive skills strategies.

The stoichiometry problems used in this study were predominantly well-defined with some characteristics of ill-defined problems. In other words, the problem will require students to use algorithms (routine set of steps to follow) and conceptual understanding to reason out a solution. Conceptual understanding may involve understanding how a particular law or principle of chemistry may be used in order to solve the problem at hand. Generally, students prefer to solve algorithmic problems because the predominant teaching approach used by chemistry teachers is

algorithmic (Haidar and Naqabi, 2008; Robinson, 2003; Gabel, 1999). Metacognitive skills problem-solving strategies require that students move away from mechanical application of known procedures to thinking about the process while solving the problem (Haidar and Naqabi, 2008). In Study 2, students were given a set of stoichiometry problems to solve before and after the MSF and MSM interventions, these are referred to as PSTs. The problems were similar to those the students were likely to experience in the school examinations. These problems were similar to those given during the 6-week training period. As in the study reported in Chapter 4, the students were given the MCAI at pre- and post-test.

5.1.3 The relative contribution of the components of metacognitive skills to problem-solving

Zohar and Barzilai (2013) commented that research involving metacognitive skills have not reported on the relative contribution of each component of metacognitive skills to the overall metacognitive skills awareness and use during problem-solving (i.e. planning, monitoring, control and evaluation; see Chapter 2). The authors also found that ‘the most frequently studied component was monitoring followed by evaluation, planning and control’ (p.31). In schools, my informal observations of teachers of stoichiometry, is that they generally tend to focus their teaching efforts on planning and monitoring skills. This was also observed by Haider and Naqabi (2008) in their study of Emirati High School students’ understanding of stoichiometry and the influence of metacognition on the students’ understanding.

In their study, Haider and Naqabi found that students of stoichiometry showed a more frequent use of the planning and monitoring component of MS. They attributed this to the general instructional approach taken by teachers of stoichiometry who they said tend to emphasize on these two components when teaching the subject.

Consequently, a better understanding of the relative contribution of each MS component could help teachers to better design instructional approaches that enhance the development of the teaching of stoichiometry. One way to do this is to investigate the relationship between each MS component with the students' achievements in problem-solving.

To investigate this issue, the students' PSTs achievement scores were used to assess their academic gains during the intervention and a Pearson's correlation matrix was computed using PSTs scores and MS component scores. Knowledge of the strength of the relationship between each MS component and PST achievement scores could give an indication of the relevance of each MS component for the students. It was also considered important to understand how the MS components are related to one another as this could potentially influence the design of instructional approaches. When a correlation between components is known, this could help teachers to understand that an instructional approach that impacts on one component might have an impact on another/other component(s). These analyses do not appear to have been conducted in previous studies.

This study was designed to address the following questions

1. Will the two instructional methods (MSF and MSM) improve students' metacognitive awareness compared to a control group? If there is any difference between the two methods, it was expected that the MSF intervention would have greater impact than the MSM intervention as it involved more explicit instructions.
2. Will instructional methods MSF and MSM improve participating students' PST achievement scores in stoichiometry problem-solving tasks compared to the control group?

3. Do significant correlations exist between; total MCA scores and PST scores, the four MCAI component scores and the PST scores, and which MS component had the strongest correlation with the PSTs total score?

5.2 Methodology

Methodological considerations are similar to those reported in Chapter 4

5.2.1 Method

5.2.1.1 Participants

Participants were final year International General Certificate of Secondary Education (IGCSE) students of chemistry from school A and school B in Harare in Zimbabwe. These schools were chosen because they have a balanced mix of boys and girls. All students followed the University of Cambridge IGCSE chemistry curriculum and they were on the course by choice. A total of 61 students took part in this study on a voluntary basis. Students were encouraged to participate and were advised that they may benefit from taking part as the content of the activities was directly related to their course of study in stoichiometry problem-solving.

There were two experimental groups, A and B. The sample consisted of 34 girls and 27 boys. Experimental Group A (MSM) had 8 boys and 9 girls and experimental Group B (MSF) had 9 boys and 12 girls. The control Group C, consisted of 13 girls and 10 boys. The three conditions were randomly allocated to the three schools. Ethical permission was obtained from the school head teacher (Appendix 15), the participating teachers (Appendix 13), participants and their guardians (Appendix 10). The two teachers who carried out the intervention were the chemistry teachers from school A. A teacher from school B was responsible for the control Group C. It was not possible to randomly allocate the teachers to the conditions as the two chemistry classes were located on different campuses of the school.

5.2.2 Measures

The students' metacognitive skills were assessed prior to and after the intervention using the metacognitive activities inventory (MCAI) (Cooper and Sandi-Urena, 2009 see Chapter 4 and Appendix 3). The MCAI inventory consisted of 27 items and used a 5-point Likert scale that ranges from 1-strongly disagree to 5-strongly agree.

Participants were given a problem-solving task (PST) pre-test following the MCAI. The chemistry test consisted of an exam type compound question which was a *well-defined problem* consisting of related sections.

The pre-test and post-test PSTs were similar in structure and task demand level, but different in content; there was a single question with several subsets, which the participants had to complete in 15 minutes (Appendices 6 and 8, Chemistry Problems). Participants had to work through each section in sequence. The scores obtained from the PST were expressed as percentages. Some of the students also took part in a semi-structured group interviews (Appendix 4) to provide qualitative data on how the participants utilized their metacognitive skills during problem-solving. This research is discussed in chapter 6. The interviews took place approximately two weeks after the post-tests.

5.2.3 Procedure

To investigate metacognitive skills, two pre-tests were administered to all three groups, one in the form of metacognitive activity inventory (MCAI) (Appendix 3), another in the form of a chemistry problem (Appendix 6). Students were told to attempt the PST in the normal way they were taught by their regular teachers. They were also told to answer the questions on the back of the of MCAI sheet. This was followed by a three-week intervention where each group was taught quantitative

chemistry (stoichiometry), two times a week for thirty minutes per lesson using questions given in Appendix 9. At the end of the intervention period two post-tests were administered to all three groups. One post-test was the MCAI, and another was the PST (Appendix 8) to assess achievement resulting from the intervention.

During the intervention students in Group A were taught using the *metacognitive skills modelling (MSM)* (Appendix 2, see also Chapter 4) and Group B was taught *metacognitive skills framework (MSF)* (Appendix 1) while the control Group(C) was taught using traditional non-metacognitive strategies.

MSM Intervention: For lesson one, the teacher of experimental Group A was asked to first distribute copies of the metacognitive skills framework. The teacher then went through the framework explaining to the students each section and its descriptors. Then the teacher used a practise problem task (Appendix 7) to demonstrate to students how to use the MSF. For example, the teacher asked the students to read the question and identify relevant and irrelevant information. After this the students were asked by the teacher to suggest a method or formula for solving the problem and if they didn't know the teacher asked them to either consult their neighbour or look up from their textbook or notes. The teacher followed through the rest of strategies written in the MSF until the problem task was solved. This was followed by another lesson where students practised problem-solving using the MSF. In week two, the students completed two more problem-solving tasks. This was repeated in week three. In week four students were given post-tests as described above.

MSF Intervention: The teacher of experimental Group B also made use of the practise problem-solving task (Appendix 7) to demonstrate metacognitive skills modelling. The students in Group B were required to verbalise their thinking or what they were doing during problem-solving (think aloud protocol, TAP) as demonstrated by the teacher.

This involved posing questions, resource identification and a recitation of affirmations as the problem-solving process occurs. Problem-solving tasks that were used in the lessons are shown in Appendix 9.

Control Condition: The teacher teaching the control Group C was asked to use explicit demonstration that shows a step by step explanation of stoichiometry problem-solving at the beginning of the lesson. This was to avoid using the metacognitive teaching strategy. The teacher was required to use a worked example given to her where participating students would try to make sense of how the problem was solved. The teacher was told that she could only help students when they asked for help. The teacher was asked to instruct the students to work individually in silence to avoid the effect of joint cognition through collaboration.

To minimise disruption of normal lessons, the students were taught after school hours during their extra-lessons slot. Lessons were run for three weeks with 30-minute sessions held on Monday and Wednesday from 3:00-3:30. Lessons were conducted in the normal teaching rooms.

The participating teachers were trained by the researcher outside school hours within the school in three sessions each, not lasting more than thirty minutes. The training did not require students to be involved. The researcher modelled the use of the metacognitive framework as an instructional tool. Using a practise chemistry problem (Appendix 7), the researcher demonstrated how to use the metacognitive framework. For example, using the problem in Appendix 7, the planning component on the metacognitive framework was taught by asking the teacher to read the question first and determine the goal, sort information into relevant and irrelevant and break down the problem into small chunks. The teacher was asked to establish the relationship among any data and then decide on a strategy or method to find a solution. This was

repeated for other components of the metacognitive framework, i.e. monitoring, control and evaluation. Specific instructions given to the teachers and the practice problem used for training are found in Appendix 7.

5.3 Results

5.3.1 Data analysis

The students' score from the MCAI was expressed as a percentage of the total points (27x5=135). Quantitative data was analysed using descriptive and inferential statistics. A two-way repeated measure analysis of variance (ANOVA) was conducted to establish the existence of any significant differences across the pre-test and post-test MCAI. The effectiveness of the two instructional methods was also compared by carrying out a two-way repeated ANOVA using the pre-test and post-test achievement scores from the problem-solving tasks (PSTs). Scores from the MCAI were correlated with scores obtained from a chemistry achievement test to see if there were any significant relationships.

5.3.2 The MCAI Scores of the Three Groups

Table 5.1 The MCAI mean percentage scores, standard deviations, skewness and kurtosis of the experimental and control groups.

Group	Measure	<i>N</i>	<i>M</i>	<i>SD</i>	Min	Max	Skewness	Kurtosis
Experimental Group A	Pre-test MCAI	17	57.76	7.52	39	70	-1.36	1.08
	Post-test MCAI	17	59.88	7.67	49	76	0.83	-0.47
Experimental Group B	Pre-test MCAI	21	67.38	7.71	52	81	-0.14	-0.29
	Post-test MCAI	21	65.10	9.38	41	77	-1.46	0.51
Group C Control	Pre-test MCAI	23	66.91	7.35	52	86	1.30	1.53
	Post-test MCAI	23	64.30	7.73	42	76	-2.58	2.44

Testing for data distribution for both MCAI (table 5.1) and PST (table 5.2) shows that the values of skewness and kurtosis fall within acceptable limits; z-score ± 1.96 at significance level $\alpha=0.05$. There is only one data set (post-test MCAI control group) where skewness and kurtosis values are outside the recommended range. This was due to two outlier data scores, which when removed would make the data set normally distributed with skewness of -0.36 and kurtosis of 0.72. As a result of these checks it appeared that parametric statistics could be used with these data.

The results in Table 5.1 show that there was a slight decrease in MCA scores over time for Group B and C, while there was a slight gain for Group A. A visual inspection of pre-test scores suggests that there could be group differences in the MCAI scores; in contrast it seemed unlikely that there were any significant differences in MCAI scores over time.

A two-way 2 (time) x 3 (groups) repeated measures ANOVA was run on the MCAI scores to examine the effect of Group and Time on the metacognitive skills awareness and use. The analyses showed that there was no main effect of time; $F(2,58)=0.74$, $p=0.395$, $\eta p^2= 0.013$, indicating that there was no significant overall improvement of students' metacognitive awareness and use over the period of the intervention. However, the analyses showed that there was a main effect of group, indicating that there were group differences in MCAI scores; $F(2,58)=6.82$, $p=0.002$, $\eta p^2= 0.190$. There was no significant interaction, indicating that effects did not vary across time and group; $F(2,58)=1.84$, $p=0.168$, $\eta p^2=0.060$.

To see if there was a significant difference between the pre-test MCAI mean scores of the three conditions a one-way ANOVA was performed and the analyses showed that there was a statistically significant difference between the mean scores of the three conditions; $F(2,58)=9.53$, $p<0.001$).

A post-hoc SLD test showed that the differences were found to be statistically significant at $p < 0.05$ between MCAI means of Group A ($M=57.76$, $SD=7.52$) and Group B ($M=67.38$, $SD=7.71$), and between Group A ($M=57.76$, $SD=7.52$) and Group C ($M=66.91$, $SD=7.35$). There was no statistically significant difference between the pre-test MCAI mean scores of Group B ($M=67.38$, $SD=7.71$) and C ($M=66.91$, $SD=7.35$). One-way ANOVA results for post-test MCAI scores showed no significant differences between the groups; $F(2, 58) = 2.09$, $p = 0.13$; Group A ($M=59.88$, $SD=7.67$), Group B ($M=65.10$, $SD= 9.38$) and Group C ($M=64.30$, $SD=7.73$).

5.3.3 Chemistry Problem-solving Task Scores (PSTs) for the three groups

Table 5.2 The PST mean percentage scores, standard deviations, skewness and kurtosis of the experimental and control groups.

Group	Measure	<i>N</i>	<i>M</i>	<i>SD</i>	Min	Max	Skewness	Kurtosis
Experimental Group A	Pre-test PST	17	66.47	18.35	35	100	0.11	-0.79
	Post-test PST	17	68.64	15.52	50	100	0.92	-0.88
Experimental Group B	Pre-test PST	21	43.57	17.90	15	70	0.038	-1.37
	Post-test PST	21	62.20	23.50	23	100	0.25	-1.27
Group C Control	Pre-test PST	23	55.04	21.84	27	93	1.10	-1.07
	Post-test PST	23	70.69	16.60	41	100	-0.24	-1.15

The mean PST scores of the three groups at pre- and post-test are shown in table 5.2. A visual inspection of the scores suggested that there might be group differences at pre-test, improvements in the PST scores for groups B and C, and, as a consequence, no group differences at post-test. In the case of the percentage increase in the PST scores (see Table 5.3), Groups B and C showed large changes over time with Group B showing the largest gain in achievement scores. The gain by Group C (the control

group) in both MCAI and PSTs scores between pre-test and post-test was surprising and required further investigation.

A 2 (time) x 3 (groups) repeated measures ANOVA was performed on the PST scores. The analyses revealed a main effect of time showing that there was an overall improvement in PST scores; $F(2,58)=35.65, p<0.05, \eta p^2= 0.381$. There was also a main effect of group showing that there were group differences in PST scores; $F(2,58)=3.52, p=0.036 \eta p^2= 0.108$, and a significant interaction showing that these effects varied across time and group; $F(2,58)=5.67, p=0.006, \eta p^2= 0.16$.

To test whether there were group differences in pre-test PST scores a one-way ANOVA was conducted. This analysis showed that there was a statistically significant difference between the pre-test means of the three conditions ($F(2,58)=6.44, p=0.003$); Group A ($M=66.47, SD=18.35$), Group B ($M=43.57, SD=17.90$) and Group C ($M=55.04, SD=21.85$). To find out where the differences lay, LSD Post Hoc analyses was carried out and these revealed that there was a significant difference between Group A and Group B, $p<0.05$. Thus, there were significant differences between the PST scores of the three groups at pre-test. Another one way ANOVA was conducted on the post-test scores and the results revealed that there were no statistically significant differences between the post-test means of the three conditions; ($F(2, 58)=1.16, p=0.32$); Group A ($M=68.64, SD=15.52$), Group B ($M=62.20, SD=23.50$), Group C ($M=70.70 SD=16.60$).

To find out whether there were significant differences in the PST scores of each Group between pre- and post-tests related t-tests were conducted. These analyses showed statistically significant differences between pre and post-test PST scores for Group B and Group C; Group B pre-test ($M=43.57, SD=17.90$) and post-test ($M=62.20, SD=23.50$); $t(20)= -4.59, p<0.001$ and Group C pre-test ($M=55.04, SD=21.85$) and post-test ($M=70.70, SD=16.60$); $t(22)= -4.26, p<0.001$.

The findings show that the PST scores of groups B and C significantly improved; Group A started out with higher PST scores than the other groups, but the scores of this group did not significantly improve; as a result of both these effects there was no significant difference in PST scores at post-test.

Table 5.3 Percentage change of MCAI and PST scores over time for all three groups.

		MCAI Mean scores			PST Mean scores		
Group	N	Pre-test	Post-test	% change	Pre-test	Post-test	% change
A	17	57.76	59.88	3.67	66.47	68.65	3.28
B	21	67.38	65.10	3.38	42.50	62.20	46.35
C	23	66.91	64.30	3.90	55.04	70.70	28.45

Results in table 5.3 show that there was a small percentage change in MCAI scores between pre-test and post-test for all three groups and this is similar to the information in Table 5.1. However, the results show a significant percentage change in PST scores for Group B and C between pre-test and post-test while there was small change for Group A. This is also similar to the information in Table 5.2

5.3.4 The Four Components of MCAI (PCME) and their Percentage change over time.

Table 5.4 shows percentage change in the MS components over time. There was no appreciable change in the way students rated their awareness and use of the MS components over time. The only large change was a 14.48% increase in the monitoring component for Group A, compared to an increase of 1.64% for Group B

while the control group reported no change as was expected. Given the low rates of change no statistical analyses were carried out on these data.

Table 5.4 Comparison of PCME Percentage change over time for all groups

Group	N	Pre-test				Post-test				% Change			
		P	C	M	E	P	C	M	E	P	C	M	E
A	17	3.40	3.19	2.90	3.22	3.47	3.37	3.32	3.28	2.10	5.64	14.48	1.86
B	21	3.70	3.70	3.36	3.70	3.82	3.74	3.41	3.70	3.24	1.08	1.64	0.00
C	23	4.00	3.60	3.53	3.72	4.00	3.60	3.53	3.74	0.00	0.00	0.00	0.54

P=planning, C=control, M=monitoring, E= evaluation

5.3.5 Correlation between MCAI scores and PSTs score

Table 5.5 Pearson's correlation between MCAI and PSTs scores for all conditions

Group	N	Pre-test	Post-test
		<i>r</i>	<i>r</i>
A	17	0.202	-0.175
B	21	0.267	0.269
C	23	-0.219	0.179

To investigate the relationships between the MCAI and PST scores correlations were calculated for each group at pre- and post-test. There were weak to moderate non-significant correlations between the MCAI and PSTs scores, with the highest correlations being in Group B. This shows that it is unlikely that these relations would occur in another independent study. In some instances, Group A post-test and Group C pre-test, a negative correlation is observed, indicating high scores on one assessment were related to low scores on the other assessment.

A more detailed analysis (Table 5.6) of each component of the MS shows a very similar pattern. Only in the pre-test for Group A did a significant correlation occur (between PST and pre-test E). Thus, there was very little evidence that one or more of

the components of the MS were related to the PST scores. This backs up the previous analysis using total MCAI scores.

Table 5.6 Pearson Correlation between PCME and PSTs scores for all conditions

Group	N		Pre-test				Post-test			
			P	C	M	E	P	C	M	E
A	17	<i>r</i>	-0.061	0.094	-0.413	0.650*	0.146	-0.245	0.002	-0.063
B	21	<i>r</i>	0.332	-0.253	-0.034	0.049	0.084	0.110	0.056	0.275
C	23	<i>r</i>	0.256	0.053	-0.203	-0.251	0.245	0.257	-0.098	-0.127

The results in table 5.6 show a significant correlation between the evaluation component and PST scores for Group A at pre-test but this is not repeated at post-test assessment indicating lack of consistency. The rest of the results show a similar pattern of low correlations or inconsistency across the groups and across time. This shows that there is little or no relationship between how students rate their awareness and use of MS components in relation to their problem-solving skills as assessed by their PST scores. This is consistent with the findings on the correlation between PST and MCAI total scores.

5.4 Discussion

The effect of using the metacognitive skills framework (MSF) and metacognitive skills modelling (MSM) on metacognitive skills awareness and use was investigated in this study. Results showed that there were no statistically significant differences between the students' pre-test and post-test MCAI scores suggesting that the instructional intervention had no effect on the students' metacognitive awareness as assessed by the MCAI. Secondly, the study investigated whether instructional methods made an improvement on the students' academic achievement and this was assessed by comparing pre-test and post-test achievement scores from PSTs. There was a statistically significant difference between the pre-test and post-test PST scores for groups B and C. This was surprising as Group A, an intervention condition involving MSM, did not show an improvement while the control condition showed an improvement in academic achievement.

The study also investigated whether there was a correlation between the metacognitive skills components and the students' PST achievement scores, and between MCAI and PST scores. Results showed neither significant nor consistent PCME-PST and MCAI-PST correlation across the conditions at each time point. The following sections contain a discussion of the results under the respective themes of the investigation and closes with a short summary and conclusion.

5.4.1 Did the instructional intervention make a difference in metacognitive awareness?

The instructional intervention methods did not appear to have made a statistically significant difference in the students' metacognitive awareness at least as assessed by the MCAI. The slight decrease in the MCAI scores for Group B is consistent with previous studies (i.e. that metacognitive skills improve) (Zepeda et al., 2015; Sandi-Urena et al., 2011), but the slight rise observed in Group A scores and decline in Group C (control) was surprising and unexpected. There are several explanations for these findings. It is possible that the slight increase in Group A's MCAI post-test mean score could be a result of a few students in the lower performance band overstating their post-test MCAI scores. Low ability students generally have low metacognitive skills (Pennequin et al., 2010; Pintrich, Anderman, Klobucar, 1994) but they also have a tendency to overstate their ability to perform academic tasks (Butler, 1998a; Meltzer et al., 1998; Alvarez and Adelman, 1986). This may not have been observed in the other groups because the other two groups may have had a lower number of low ability students as shown by the chemistry achievement scores between pre-test and post-test.

What is most surprising is that although the metacognitive skills framework essentially provided specific step by step guidance on the use of metacognitive skills during task performance, students did not show an increase in their self-reported metacognitive skills awareness and use. Furthermore, these findings are different from those obtained in Chapter 4. This could possibly indicate that the students remained conservative in their self-report and this has been reported in previous studies (Sandi-Urena et al., 2011; Delvecchio, 2011) for the reasons suggested previously.

5.4.2 Which instructional intervention was more effective in raising achievement?

Groups B and C showed a significant improvement in achievement scores. Group B (MSF) experienced the highest improvement in achievement scores (46.35%). This suggests that the intervention administered to this group was more effective than the one administered to Group A (3.2%) which did not show a significant improvement in achievement scores. In other words, the metacognitive skills framework appears to have been more effective in helping students solve stoichiometric problems than the metacognitive skills modelling (MSM). This was consistent with the prediction made. The MSF is a more explicit metacognitive instructional method and more explicit metacognitive instructional methods appear to help students to improve on their academic achievement (Zepeda et al., 2015; Ellis et al., 2014; Sandi-Urena et al., 2012; Pennequin et al., 2010).

The control group's surprising results will require further investigation. Several factors could account for this outcome. For example, this group was preparing for external assessment in chemistry and this could also have added to their motivation and commitment to the learning tasks and this could have led to this group achieving high scores in PSTs. Another reason could be that the group was made up of high ability students as shown by the large proportion of high achieving students. More able students are likely to show a strong correlation between their achievement scores and metacognitive awareness (Cooper and Sandi-Urena, 2009; Young and Fry, 2008)

5.4.3 Was there a correlation between problem-solving achievement scores and MCAI scores and which MS component has the strongest correlation with problem-solving?

The analyses showed that the correlations between MCA and PST were weak and inconsistent both across the groups and at each time. The same pattern was observed

in the analyses of correlation between MS components and PST scores. The results suggest that MCAI may not be a good tool for assessing changes in students' metacognitive skills awareness and use. Previous studies have shown that students who made gains in metacognitive skills also improved their problems solving skills (Zepeda et al., 2015; Cook et al., 2013; Sandi-Urena et al., 2012; Pennequin et al., 2010).

There was no significant correlation between the MS components and PST scores. This could possibly suggest two things. Firstly, it could mean that there is no relationship between how students rate their awareness and use of metacognitive skills components during problem-solving and their problem-solving skills. Secondly, it could mean that the MCAI is not an effective tool for assessing metacognitive skills. Lack of correlation between components of MS and the students' achievement scores agrees with the lack of correlation between the overall MCAI scores and the achievement scores from PSTs. This could possibly mean that the MS components do not necessarily make an individual contribution to the students' overall MS awareness and use.

There are a number of factors which influence the enhancement of metacognitive skills awareness and use, and improvement in achievement scores. These could help to explain the findings in the present study. Ill-defined problems are reported to be more effective in developing metacognitive skills than well-defined problems (Cooper and Sandi-Urena, 2009).

This study involved predominantly the use of well-defined problems. It is also important to note that most previous studies have been carried out at tertiary level and involved large samples. Similar percentage point changes in between MCAI pre-test and post-test were reported (Sandi-Urena et al., 2011), but the sample was nearly

twenty times larger than the sample sizes used for this study and so had higher statistical power. Delvecchio (2011) attempted a similar study with high school students with a similar sample size as the one used in this study, but she failed to obtain results with a statistically significant difference.

5.5 Limitations

The MCAI was designed and validated for use among university students. Despite their ease of use and convenience, self-report measures as a single source of data have been reported to be problematic because ‘they have been shown to be poorly correlated to concurrent measures of metacognitive skills’ (Cromley and Azevedo, 2006; Veenman, 2011; in Zohar and Barzilai, 2013 p.28). To overcome this difficulty Sandi-Urena et al., (2011) suggested the use multi-method approach to collect data studies on metacognition.

As in the study reported in Chapter 4, it was difficult to randomly allocate the participants to conditions because they were located in three different locations. Like in the previous study, ability levels were not controlled across groups and this makes it difficult to be sure that the intervention was the only factor responsible for the outcomes. A further limitation was that both groups showed significant differences in both MCAI and PST pre-test scores; ideally, there shouldn’t have been differences, but there seemed to be pre-existing causes for these differences.

5.6 Implications for teaching and learning

The potential contribution of the MSF as a metacognitive instructional method to teaching and learning is quite promising. The MSF has shown that it is a better metacognitive instructional method by a significantly high percentage improvement in problem-solving achievement scores. This suggests that teachers of stoichiometry can

have more effective lessons by incorporating the MSF in their instructional strategies. It also seems likely that the MSF can also be used by teachers of mathematics and physics to train students to solve algorithmic problems. It is important to remember that both MSM and the MSF are explicit metacognitive instructional methods differing in the extent to which they are explicit.

5.7 Summary and Future Research

The lack of correlation between MCAI scores and PST scores, PCME and PST scores was disappointing. Previous studies have recorded a link between MCAI and achievement in chemistry. What has not been studied is the relationship between PCME ratings and achievement scores. As stated previously, there appears to be a need to find another assessment tool which can assess metacognitive activities in students more sensitively than MCAI. An ideal assessment instrument would be one which is validated for use among secondary school students. The anomalous result concerning control group required further investigation (see Chapter 6) and the findings from teacher interviews were reported in chapter 7 which investigated the teaching approaches used by the regular teachers of all the groups.

The study investigated the effectiveness of MSF and MSM as metacognitive instructional interventions on the enhancement of students' metacognitive skills awareness and use, and students' academic achievement. Results showed that the intervention made no significant changes to the students' metacognitive skills awareness, while there were significant changes in the students' achievement scores with Group B recording the highest increase in PSTs scores. It appears that the MSF was more effective in helping students improve on their problem-solving skills in stoichiometry than the MSM. However, the control group reported a higher achievement score compared to experimental Group A, indicating that there could

have been some variables which helped the control group. There was weak and inconsistent correlation between MCAI and PST scores and a similar pattern was also observed between MS components and PST scores. The anomalous result for the control group necessitated further enquiry, results of which are reported in Chapter 6.

Chapter 6: Study 3: Assessing similarities/differences of metacognitive skills and motivation of students of stoichiometry

6.1 Introduction

This chapter concerns the self-perceptions of students who took part in the research described in Chapter 5, where students in the experimental and control groups had similar MCAI and PST scores at post-test, although Groups B and C had significant increases in their PST scores.

The aim in this chapter is to try to better understand the reasons for the similarities at post-test using semi-structured group interviews. Three issues are addressed in the analyses; similarities of students' metacognitive skills, level of MS skills use across the groups and students' motivation levels. Students' motivation could influence their engagement with the problems and so affect both the MCAI and PST scores and might help explain the increases in the PST scores of Groups B and C. Group interviews were used to collect information. A group interview is a technique used to collect qualitative data and it involves selected participants who do not necessarily represent a particular sampling of a given population but have a purposeful topic to explore (Thomas et al., 1995; see Chapter 3).

It was thought that the discussions in group interviews composed of participants who took part in the research would provide useful qualitative information about the thinking of the participants that would help to understand the pattern of responses identified in Chapter 5. It was decided to use similar questions for the three interview groups (i.e. one from each of the three conditions) so that comparable information would be obtained from each. In group interviews, the participants are usually selected based on the criteria that they have sufficient knowledge within their age-

range to make a meaningful contribution to the topic to be discussed and that they possess comparable socio-characteristics and would experience no discomfort in interacting with each other and the interviewer (Richardson and Rabiee, 2001; Burrows and Kendall, 1997).

6.1.1. Similarity of metacognitive skills.

Previous work (as discussed in Chapter 1) has suggested that teaching metacognitive skills can improve students' learning and problem-solving skills (Zepeda et al., 2014; Zohar and Barzilai, 2013; Pennequin et al., 2010; Schraw et al., 2006). However, as indicated by the findings reported in the previous chapter, teaching metacognitive skills to students is not necessarily sufficient to improve their scores on metacognition or their problem-solving skills in stoichiometry.

To better understand the reasons for similar MCAI scores at post-test, interview groups were asked questions about several aspects of their use of metacognitive skills. The questions in the interviews concerned significant processes that have been identified in metacognitive skills training, i.e. planning, monitoring, control and evaluation (Zimmerman and Pons, 1986). Given the lack of statistically significant differences in MCAI scores at post-test (Chapter 5) it was expected that all three groups would report using metacognitive skills to the same extent. The first question considered in this study was; were there similarities or differences in students' use of metacognitive skills across the three conditions?

6.1.2. The use of different components of metacognitive skills awareness across the three groups.

Obtaining self-reports from students about their use of metacognitive skills provides information about which skills were thought to have been used more often and which skills were used less frequently. Previous research on metacognition has rarely

considered this issue by investigating different components of metacognition. It might be expected that some metacognitive skills are more likely to be used than others. Research on the use of metacognitive skills in stoichiometry suggests that students tend to have a more developed use of planning and monitoring strategies than other MS components, and it is suggested that this is so because teachers of stoichiometry focus more on teaching planning strategies, using algorithmic and symbolic approach (Haider and Naqabi, 2008; Robinson, 2003; Gabel, 1999).

Haider and Naqabi's findings suggest that students predominantly use planning and monitoring skills during problem-solving in stoichiometry because these are the skills teachers and textbooks appear to focus on. However, Winne and Hadwin (1998) in their model of regulated learning suggest that monitoring and control require students to develop a conceptual understanding of stoichiometry. MCAI pre-test and post-test results in Chapter 5 indicated that students across the three groups reported a slightly higher level of awareness and use of the planning and evaluation skills, contrary to Haider and Naqabi's findings. Given the discrepancies in previous findings it was thought useful to study these processes in the students who took part in the metacognitive skills intervention to see if any of the findings could be replicated.

It was hoped that the use of semi-structured interviews would help to provide an understanding of the students' perception of how they used their metacognitive skills components during problem solving in stoichiometry. Thus, the second question considered in this study was; what was the general level of metacognitive skills awareness reported across the three groups and across the different components of metacognitive skills? It was predicted that the three groups would report similar general levels of metacognitive skills awareness and use across all the MS

components. Based on previous research it was expected that planning might be reported to be used more than the other components

6.1.3. Motivational orientation

As stated previously, teaching students metacognitive skills alone is not sufficient to improve both their metacognitive awareness and use and their achievement in stoichiometry. One of the possible explanations for the lack of significant differences between the three groups in PST and MCAI scores could be similarities in motivation. Knowing cognitive strategies and metacognitive strategies (or metacognitive skills) is generally not sufficient to raise student achievement; students must of necessity be *motivated* to make use of the strategies (see Chapter 2) and should also be able to regulate their cognition and effort as they engage with the task during task performance (Pintrich, 1988; Pintrich, Cross, Kozma, and McKeachie 1986). While there are indeed classroom situations where motivation can be fostered, evidence from research suggests that students' perception of their personal motivation and beliefs about the learning tasks are pertinent to how they engage cognitively and how they perform in the classroom (e.g., Ames and Archer, 1988; Nolen, 1988).

Although researchers have written positively about the benefits to the learner of developing metacognitive awareness and metacognitive skills, it is important to critically consider how differences in individual student motivation are linked to the three components of self-regulated learning. This could help to describe and provide an understanding of how students' individual characteristics are connected to their cognitive engagement as well as to their academic performance in class (Snow, 1989; Weinert, 1987). Cooper and Sandi-Urena (2009) reported that while metacognitive strategies are known to improve students' performance and achievement in general,

it is important to take into account the importance of motivation and related cognitive factors. Because of this, it was decided to ask students about their motivational orientation during problem-solving tasks.

The student's motivation theoretical framework was conceptualized through the 'adaptation of expectancy-value model of motivation' (Pintrich and De Groot, 1990 p.33). Proposed in this model are three motivational components which can be linked to the three components of self-regulation. There is the *expectancy* component which encompasses the students' beliefs about their capacity to perform a learning task. Although this component of the learner's motivation has been conceptualised in different ways in literature, the fundamental construct has to do with the learner's personal beliefs that they are capable of task performance and that they are ultimately responsible for their own performance (Pintrich and De Groot, 1990). In other words, the expectancy component requires that students be able to answer the question 'Can I do this task?' (Pintrich and De Groot, 1990).

Different attributes of the expectancy component of motivation are said to be related to the students' metacognition, the students' cognitive strategy use and the way the students manage their effort during task performance (Pintrich and De Groot, 1990). Broadly, research findings suggest that those students with the belief that they are capable of executing a task are more likely to use metacognition during task performance, make use of a greater variety of cognitive strategies, and they are likely to be more persistent at task performance than students lacking this (Paris and Oka, 1986; Schunk, 1985). Consequently, it is reasonable to expect that students' expectancy level will be related to their metacognitive skills.

The value component includes the learners' goals and beliefs, concerning their perception of the importance of the task, and how interesting they find the learning

task. This component requires students to respond to questions such as 'Why am I doing this task?' Research suggests that there is increased engagement in metacognitive activity, cognitive strategy use and effective management of effort when students are motivated by the desire not only to learn and master skills, but also believe that the task is important and interesting (Ames and Archer, 1988 Nolen, 1988; Paris and Oka, 1986). As all participating students in this study were final year IGCSE students, their need to do well in their chemistry examinations should have provided sufficient motivation to engage with the learning tasks.

The third component is the affective component, and this includes the students' emotional response to the learning task. This component requires the students to respond to questions such as 'How do I feel about this task?' (Pintrich and De Groot, 1990). There are various affective responses that students may present when confronted with a learning task. For example, students might show anxiety, anger, excitement, pride, guilt etc. Wigfield and Eccles (1989) suggest that the most important affective response within a school learning context is test anxiety. In general, students who exhibit high anxiety levels lack persistence and tend to avoid tasks that they find difficult (Hill and Wigfield, 1984). The affective component of motivation can be linked to metacognitive experiences of feeling of difficulty and metacognitive experiences of feeling ease of task (Efklides et al., 1999).

Metacognitive experiences are a result of the monitoring function which then serves as an input for the metacognitive control function (Efklides et al., 1999). When students feel that the task is difficult (through the metacognitive skills function) they can either persist or give up. The third research question investigated was; was the motivation to solve stoichiometry problems similar in all three groups of students? In other words, did the students show a similar response to the expectancy, value and

affective components of their motivation as they engaged with stoichiometry problem-solving task? It was predicted that there would be similar levels of motivation in all three groups.

6.1.4 Assessing evidence

It was expected that the level of metacognitive awareness would be demonstrated by the knowledge of strategies related to the use each MS component. Participants demonstrating more knowledge of these strategies would be described as possessing a high level of metacognitive awareness and those with less knowledge would be described as possessing low metacognitive skills awareness. On the other hand, similarities/differences in metacognitive skills awareness and use would be judged by the similarity/difference of responses given by the participants from each group. In addition, similarities/differences in motivational orientation would be judged by the responses given by the participants to questions related to three components of motivational orientation.

It was anticipated that the discussions and answers from the three groups would provide an indication of whether there were similarities or differences in metacognitive awareness and motivation. In the case of different groups providing similar answers to the questions, this obviously would provide positive evidence to support the case that the three groups were at comparable levels. In contrast, if one group showed higher levels of metacognitive awareness or motivation than another group this would indicate differences in their levels. It was anticipated that in some cases students from different groups might provide different answers and explanations, but these would be at similar levels of sophistication.

To summarise: The lack of statistically significant differences in MCAI scores at post-test (Chapter 5) necessitated a further inquiry into the students' self-reported metacognitive skills awareness and use. It was expected that all three groups would report using metacognitive skills to the same extent as suggested by findings from the study described in Chapter 5. The first question researched was; were there similarities in students' self-report about their metacognitive skills awareness and use across the groups?

Previous research on metacognition has rarely considered students' self-report about their use of metacognitive skills, yet this is likely to provide information about which skills were thought to have been used more often and which skills were used less frequently. It might be expected that some metacognitive skills are more likely to be used than others as suggested by Haider and Naqabi (2008). Given the discrepancies in previous findings, it was thought useful to study these processes in the students who took part in the metacognitive skills intervention. Therefore, the second question considered in this study was; what was the general level of metacognitive skills awareness reported across the three groups and across the different components of metacognitive skills?

Knowledge of metacognitive strategies alone may not be sufficient to enable students to improve their problem-solving skills in general and specifically in stoichiometry. Students should be willing and be motivated to apply not only their knowledge of metacognitive strategies, but also manage and control their effort during task performance. Therefore, the third research question addressed the following issue; was the motivation to solve stoichiometry problems similar in all three groups of students? In other words, did the students show a similar response to the expectancy,

value and affective components of their motivation as they engaged with stoichiometry problem-solving task?

6.2 Method

As described in Chapter 3, the group interview method was chosen for this study. The optimum number of participants in an interview group varies according to the complexity of the research question. However, a number of researchers including Krueger and Casey (2000) suggest one should have between six and eight participants although in certain cases the number can increase to ten. For simple research questions, group interviews with three or four participants are considered to be ideal (Burrows and Kendall, 1997).

6.2.1 Participants

This was considered to be a simple study therefore six students were chosen from each group. Group A: 4 boys and 2 girls. Group B: 3 boys and 3 girls Group C: 3 boys and 3 girls. Students in each group represented high, middle and low achievers. This was done in order to get a balanced self-report across all achievement groups. Students were selected using their achievement scores from post-test problem-solving tasks. High, medium and low achieving students were students with A grade (80-100), B/C (65-79), C/D (50-60) respectively.

The participants agreed voluntarily to participate in the interviews. Those who were selected, but declined to participate were replaced by others from the same achievement band who volunteered to take part. The students were told that they would be asked not to leave the interview before it was finished, but if they decided to leave, data collected up to the point of their departure would be used in the analyses.

There was a last minute decline from one participant from Group A and there was no time to invite a reserve participant, therefore Group A had only five participants.

Questions: The question used for assessing metacognitive skills awareness and use were obtained from the MCA inventory. There were four questions chosen for each MS component (see appendix 4). Questions used to facilitate the students to report their motivational orientation were designed using components of motivation as described in the introduction above. The questions were designed to allow students to report the expectancy, value and affective components of motivation. The questions were created by the author from theory of motivation, adopting the perspective given by Pintrich and De Groot (1990).

6.2.2 Procedure

The group interviews were conducted four weeks after the end of the study described in Chapter 5. Each group was interviewed in a quiet room provided by the school administration within the school. The students were reminded before the interview began that the conversation will be recorded and would later be transcribed for analysis. Each group was asked the same questions (Appendix 4). Each interview lasted for approximately 15-20 minutes depending on the level of engagement. Questions were usually answered voluntarily, but sometimes it was necessary to involve participants who remained quiet by asking follow-up questions such as 'X do you agree with what has been said by Y and can you explain why'.

6.3 Transcription and analysis of results

The interview questions for the group interviews with the students were designed to find more about the students' metacognitive skills awareness as well as their motivational orientation during problem-solving tasks. Interviews from the three

groups were transcribed and analysed, and the students' answers were put into four categories of metacognitive skills (planning, monitoring, control and evaluation). A table also recorded responses to questions on motivational orientation (appendix 20).

The data from the semi-structured interviews with the students and teachers was analysed using thematic analysis (Braun and Clarke, 2006). I chose thematic analysis because there were specific preselected patterns and themes to be considered across the data collected. For example, responses could show that participants were aware of planning, control, monitoring or evaluation strategies. During data analysis, I focussed my attention on the emergence of the preselected themes, i.e. components of metacognitive skills.

Data was coded to identify the four components of the metacognitive skills i.e. planning (P), monitoring (M), control(C) and evaluation (E). For example, when students were asked 'Did you always read the *whole* problem first? A response such as *I will read the entire question, so that I don't have to keep referring back to the question or Yes, I always read the whole question* indicated an awareness and use of the planning component of metacognitive skills. These responses would be coded with a P indicating awareness of planning. This was repeated for other components across the data set.

The questions asked were designed to obtain responses that showed an awareness and use of each of the four components of metacognitive skills and the students' motivational orientation. All the questions and their examples of response or a summary of the students' responses were put into tables (appendices 16-21). The tables allowed responses of students across the three conditions to be compared easily. In some cases, students' responses were broken down into subcategories. For example, under the *planning* category the response to the question 'did you always

read the whole question before attempting to answer it?'; the response was broken down into 'reads the whole question and gives a reason', 'does not read the whole question'. In certain cases, there was an overlap of responses between different questions. Experimental condition A was the least interactive and as a result sometimes a single response appears as it was sometimes difficult to get responses from everyone in the group.

6.3.1 Planning

On the planning aspect of the metacognitive strategies, most students reported that they read the whole question, with some reporting that they isolated relevant information before attempting to answer the question. When students were asked; 'Did you always read the *whole* problem first? Their response was similar across all three groups. For example, Ruth from Group A said *I will read the entire question, so that I don't have to keep referring back to the question* and Ben from Group B responded *Yes, I always read the whole question*. Most students from Group C responded affirmatively to the question except for J and two others from Group B, T and M. The students gave a range of reasons for reading the whole question and these included the need to understand the requirements of the question, to avoid having to keep referring back to the question and the need to avoid making errors.

In addition, the students reported breaking long questions into smaller manageable chunks and thinking about the relevant strategy to use to solve the problem task. For example, all students suggested that they would think of an appropriate formula to use in solving a numerical problem task. Thus, there is evidence that students followed the suggestions made during the intervention where they were instructed to read the whole question, break it down (if long) into small chunks, extract relevant

information and think of the appropriate strategy to use before attempting to answer it. These strategies were adopted by students in the two groups indicating a similarity across the groups in the use of planning. However, the control group also gave similar responses.

6.3.2 Monitoring

When students were asked whether they revised their procedures and questioned themselves about the correctness of the methods they were using while solving numerical problems, there was no common response across the three conditions. For example, R from Group A said *I revise to make sure that I am on the correct path*, while B from Group B said *Four out of ten times (40% of the time) I do revise* and N from Group C said *It depends, if the question was hard I would have to go back and make sure that I have done everything right and if that's easy I would not go back to check*. Most students across the three conditions responded that they did revise their procedure as they solved numerical problems. However, they responded differently to the question concerning self-reflection on the correctness of the method employed; do you question yourself whether you are using the correct method while solving the problem? Some students responded that they always questioned themselves about the correctness of the method while others reported that they did not question themselves about the correctness of the method while solving a stoichiometry problem.

For example, all students from Group A except one, said that they do not question the correctness of their method while solving a stoichiometry problem with student F saying *'if you start questioning the correctness of the method you can begin to doubt and may end up changing the correct thing in the process'*. The majority of students from Group B responded affirmatively to the question e.g. S from Group B said *I do it*

a lot actually because sometimes like, most of the time when I was doing my work previously I would make a lot of silly mistakes, but these days I am a bit careful. There were mixed responses from Group C with some students saying they do ask themselves and others saying they do not ask themselves e.g. student K said *Ah I always ask myself because it's a must to know the correct method so yeah.*

There is evidence that some students from both experimental groups adopted *some* monitoring strategies as recommended during the intervention where they were encouraged to check their steps and question the correctness of their method while solving stoichiometry problems. The evidence from the analyses shows that there were differences and similarities of metacognitive awareness with respect to the monitoring component of MS across the three groups and within the groups. In general, the three groups reported similar metacognitive awareness and use with respect to the monitoring component. The analyses show that Groups B and C answered more questions affirmatively, indicating a higher level of planning compared to Group A.

6.3.3 Control

When the students were asked what they would do if they found that they were using a wrong method, there were mixed responses. Students from experimental Group B and the control group reported that they would consult the textbook or ask someone more knowledgeable such as the teacher. D from Group B said *I will check from the textbook, maybe I would have forgotten the equations so I will go back to the equation and check if the equations are correct then I enter the information that is in the question, while P from Group C said I will try to check some information in the book and if I see that the information in the book is difficult to understand then I will seek help from my colleagues and then if my friends don't know how to help me then I will*

go and ask the teacher. Students from the experimental Group A reported that they would think of a new method by reviewing the information given in the question e.g. F from Group A said *I think of another method.*

Although all students reported that they either consulted the textbook or asked someone else for assistance, some students in Group A expressed some reservations about asking their peers or the teacher. While there is evidence that students from both experimental conditions generally followed some control strategies suggested during the intervention, where they were advised to consult the textbook or notes, to ask for assistance from the teacher or more knowledgeable peers, the same strategies were also adopted by the control group which was not taught these strategies. Group A's depth of discussion and responses to questions about the monitoring strategies revealed a low level of metacognitive skills awareness and use compared to Group B and C. For example, when asked; what do you do when you find out that the method you are using is incorrect? F from Group A responded without giving further details *I think of another method* while the rest of the Group Agreed.

Responses from groups B and C were similar. For example D from Group B said *I will check from the textbook, maybe I would have forgotten the equations so I will go back to the equation and check if the equations are correct then I enter the information that is in the question* while P from Group C responded *I will try to check some information in the book and if I see that the information in the book is difficult to understand then I will seek help from my colleagues and then if my friends don't know how to help then I will go and ask the teacher.* Group B and C appeared to be more consistent in their report on application of control strategies than Group A, therefore there were differences between the three groups' self-reported metacognitive awareness with respect to the control component of the MS. The analyses also show that Group A

reported a lower level of metacognitive skills awareness and use compared to Group B and C, while Group B and C reported similar levels.

6.3.4 Evaluation

The students' response to the question about how they checked the effectiveness of the method used to find a solution show that all students across the three conditions believed that carrying out a mathematical proof on a problem-solving strategy involving an equation was the best way to evaluate the correctness of a solution. For example, J from Group A said *I can try to prove it mathematically, i.e. I try to calculate reverse wise* and T from group said the same thing but in a different way *You use the back method*; Se from Group C gave a similar response but he also gave an example to elaborate on his response Se: *I work it out to the same, like finding the number which is given right, to the answer I got. Like if you want concentration, if you then change it to find the number of moles which you were given with the concentration you got*. It appears this is the strategy taught by the regular teachers of the groups because it is not part of the evaluation strategies suggested during the intervention. However, not all students could support their claim when they were challenged about the correctness of such an approach since such equations can always be satisfied even if the numerical value of the calculated quantity is incorrect.

Some students from experimental Group A reported that they did not check the reliability of their method (e.g. M), while others from the same group reported that they consulted the textbook or looked at their notes to check if their method was correct (e.g. CT). Generally, all students from both experimental groups and the control group reported either consulting the textbook, asking the teacher or their peer to verify the effectiveness of their method as advised during the intervention. While there is evidence, that the students from the experimental Group adopted evaluation

strategies taught during intervention sessions, the same strategies were also adopted by the control group making their responses to the questions similar. Although there were more students from the control group reporting the use of evaluation strategies than there were from intervention groups, there were no differences in the responses given by the students from the three groups, showing that the students' self-reported metacognitive skills awareness was similar across the groups. Students from Group B and C gave similar but more elaborate responses to the questions on evaluation strategies compared to Group A. This suggests that Group B and C reported a higher level of metacognitive skills awareness than Group A.

6.3.5 Motivation

Table 6.5 shows the responses given by the students to the questions asked to explore their motivation towards stoichiometry. Generally, all students reported that stoichiometry is a challenging topic. There was a difference of opinion regarding what was hard about stoichiometry, with some students such as T from Group B saying stoichiometry is *the hardest topic in chemistry, that's just plain simple*. R from Group A argued that whether a problem is difficult or not depends on how the question is structured and suggested that for long questions the difficulty lies in identifying and extracting the relevant information. When asked to express their views on the problem tasks, most students reported that they found the tasks challenging but interesting. For example, B from Group B said *I found the tasks interesting and I even 'invented' my own formula* while N from Group B said *I found them very interesting...* Most students responded that they felt frustrated if they encountered a difficult problem task which they are unable to tackle. A few students reported that they did not experience frustration; rather they try to find a way of solving the problem e.g. R from Group A. There were mixed responses from those students who reported

experiencing frustration on what to do when confronted with a challenging problem task.

Some said they would ask for help from colleagues, while others said they would continue putting more effort to try and solve the problem (e.g. F from Group A; TN from Group B) while D from Group B said *I will just skip the problem and move on*. These responses show some differences and similarities in students' motivational orientation but overall, the students across the three groups reported similar and positive response with regard to the affective component of their motivational orientation. Generally, they also responded positively to the questions on expectancy and value components of their motivational orientation. The analyses indicate that all three groups had similar motivational orientation and there was no marked difference in the level of their motivational orientation.

6.4 Discussion

This study was concerned with investigating; whether there were similarities across the three conditions in students' metacognitive skills awareness and use, including the four components of metacognitive skills, and whether their motivational orientation during problem-solving in stoichiometry was similar. In general, there were many similarities in the answers across the three conditions and these will be discussed in the subsections below. The final section gives an overview of the findings.

6.4.1 Planning strategies

The majority of the students in all three conditions reported similarities in the metacognitive skills awareness with respect to the planning component. For example, students from all three conditions reported that they read the whole question before

attempting to solve the problem. They also reported that they isolated relevant information and thought of an appropriate strategy required to solve the stoichiometry problem. For example, R from Group A said *I will read the entire question, so that I don't have to keep referring back to the question* and Ben from Group B responded *Yes, I always read the whole question* while S from Group C said *Yes, (I read) to avoid mistakes*. The analyses also show that students across the three groups reported similar levels of metacognitive skills awareness and use. These similarities could be due to a number of reasons, some of which have been discussed in the introduction above.

Haidar and Naqabi (2008) investigating Emirati high school students' understandings of stoichiometry, found that out of five metacognitive strategies comprising of awareness, self-appraisal, monitoring, engagement and planning, students reported the highest use of the planning strategy because students were trained during lessons to follow a particular set of steps in solving numerical problems. It is therefore unlikely that the intervention had an effect on the students' awareness of the planning component of their metacognitive skills as the control group reported similar awareness. This is consistent with the findings in the previous study reported in Chapter 5 where there were no statistically significant differences between the groups' MCAI means in planning.

6.4.2 Monitoring strategies

There were also similarities across the three conditions in metacognitive awareness with regards to the monitoring component. Most of the students across the three conditions reported that they did revise their steps as they solved a stoichiometric problem task. For example, R from Group A said *I revise to make sure that I am on the correct path* while B from Group B said *Four out of ten times (40% of the time) I do*

revise and N from Group C said *It depends, if the question was hard I would have to go back and make sure that I have done everything right and if that easy I would not go back to check.*

All students but one from Group A reported that they did not question the correctness of their method during the process. For example, F said *'if you start questioning the correctness of the method you can begin to doubt and may end up changing the correct thing in the process.* The majority of students from Group B responded affirmatively to the question e.g. S from Group B said, *I do it a lot actually because sometimes like, most of the time when I was doing my work previously I would make a lot of silly mistakes, but these days I am a bit careful.* There were mixed responses from Group C with some students saying they do ask themselves and others saying they do not ask themselves e.g. student K said *Ah I always ask myself because it's a must to know the correct method so yeah.*

There were more similarities than differences within and across the groups in the students' self-reported metacognitive skills awareness and use with respect to the monitoring component. However, Group B and C students appear to have reported a higher level of MS awareness and use than Group A. In general, all three conditions demonstrated *similar* but moderately weak metacognitive skills awareness with respect to the monitoring component. The similarity is consistent with findings in chapter 5 where the MCAI mean scores for monitoring showed no significant statistical difference. Haider and Naqabi's findings suggested that students tend to exhibit a high level of monitoring skills because this is what teachers of stoichiometry tend to emphasise. However, the weak metacognitive awareness with respect to monitoring skill reported by the groups could be ascribed to the students' lack of

conceptual understanding of stoichiometry, which according to Winne and Hadwin (1998) is required for students to develop MS for monitoring.

6.4.3 Control strategies

There were similarities and differences in the responses given by students in all three conditions indicating that their awareness of control strategies was not comparable. For example, when asked; what would you do if you see that the method you are using is incorrect? F from Group A responded *I will think of another method* and the rest of Group A agreed with him. Responses to the same question by Group B and C were similar and demonstrated depth of knowledge and understanding of MS control strategies; for example D from Group B said *I will check from the textbook, maybe I would have forgotten the equations so I will go back to the equation and check if the equations are correct then I enter the information that is in the question* while P from Group C said *I will try to check some information in the book and if I see that the information in the book is difficult to understand then I will seek help from my colleagues and then if my friends don't know how to help then I will go and ask the teacher*. Thus, there were similarities of MS awareness and use of the control component between Group B and C while Group A differed from both groups. Group B and C also showed a higher level of MS awareness and use with respect to the control component compared to Group A. Perhaps the students of Group B and C had a better developed conceptual understanding of stoichiometry which is required for the development of the MS control function (Winne and Hadwin, 1998).

This observation is corroborated by the MCAI control component mean scores in chapter 5 which were higher for both Group B and C than for Group A. It was predicted that all groups would report similar MS awareness and use as there were no statistically significant differences between the groups' mean scores for the MS

control component. It was also predicted that all the groups would show no difference in the level of their MS awareness and use across the components.

6.4.4 Evaluation strategies

There were similarities across three conditions with regards to the evaluation component. The majority of students from all three groups reported that they consulted the textbook or their notes to check the correctness of their strategy. They also reported that they consulted their peers to check the accuracy of their solution. All students also reported that they used the mathematical proof, which they referred to as the back method, to evaluate the accuracy of their solution e.g. J from Group A said *I can try to prove it mathematically, i.e. I try to calculate reverse wise* and T from group said *You use the back method*; Se from Group C responded *I work it out to the same, like finding the number which is given right, to the answer I got. Like if you want concentration, if you then change it to find the number of moles which you were given with the concentration you got.*

There were more students from the control group who reported using evaluation strategies compared to the intervention groups. This partly agrees with the MCAI statistical data reported in chapter 5. As in other cases above this is surprising since the control group received no training. The fact that all students from the three conditions reported using a similar method of evaluating their solutions could indicate that this is possibly what their regular teachers taught them.

The students' focus on obtaining the correct answer ignoring the conceptual correctness of the strategy employed suggests a lack of conceptual understanding by the students (Winne and Hadwin, 1998; Gabel, 1999; Robinson, 2003; Haidar and Naqabi, 2008). The elaborate responses given by groups B and C to some questions could be an indicator that the students from these groups had a slightly elevated level

of metacognitive skills awareness and use with respect to the evaluation component compared to Group A. The basic level of MS awareness and use was similar across all groups, but there were some differences between groups in the reported use of evaluation.

6.4.5 Motivation

There was no evidence to suggest that students across all three conditions lacked positive motivational orientation. The responses given by all students across the three conditions demonstrated a positive expectancy and the value components of their motivation (Pintrich and De Groot, 1990). In other words, they reported that they could solve stoichiometry problem tasks and they understood why they had to complete these tasks. For example, when the students were asked whether they found the questions easy or difficult their responses varied; for example, some (Group A) *said they were fine*, others (Group B) *said we found them interesting*, while others (Group C) *said they were challenging but we could answer them*. As described earlier, students' perception of their personal motivation and beliefs about the learning tasks are pertinent to how they engage cognitively and how they perform in the classroom (e.g., Ames and Archer, 1988; Nolen, 1988).

Although all students reported that they believed stoichiometry to be a difficult topic, they generally responded positively to questions about the affective component of their motivation, i.e. they were not discouraged when confronted by a difficult problem task. For example, when asked how they would react when they find a question to be difficult they responded that they would persist rather than give up with others suggesting that they would think of a different strategy to solve the problem or ask for help from more knowledgeable peers e.g. *Ru from Group A said I don't feel frustrated rather I think of another method* and *TN from Group B said I feel*

encouraged to try and solve the problem while J from Group C said I will go over the textbook again and again just to check what am I missing, then I will go back to the question

These responses reflect what was reported by Paris and Oka (1986) and Schunk (1985) that students with the belief that they are capable are more metacognitive in their engagement during task performance, make use of a variety of cognitive strategies and they are likely to be more persistent at task performance (rather than give up) than students lacking the belief. The analyses show that there were similarities in the students' motivational orientation across the three groups and there were no differences in the students' level of motivational orientation.

6.5 Summary and conclusion

This study investigated whether there were similarities and differences in the three groups' metacognition and motivation. The analyses showed that in general students' responses about the planning and monitoring components of MS were similar across the three groups. In contrast, Group B and C appeared to be more consistent in their report on application of control strategies than Group A. The analyses also showed that in general, Group A reported a lower level of metacognitive skills awareness and use compared to Group B and C, while Group B and C reported similar levels.

At pre-test Group A had significantly lower MCAI scores than Group B and C, and although there was very little change in the mean scores, at post-test this difference was no longer significant. Consequently, the group interviews and MCAI scores appeared to show that Group A had less developed metacognitive skills. Consequently, the findings from the group interviews give some support for the differences between the groups in metacognition as assessed by the MCAI.

Overall, there were no noticeable differences in students' motivational orientation across the three conditions. The students across the three groups reported positive expectancy, value and affective components of their motivational orientation. These findings fail to account for significant increases in PST scores in Groups B and C as being caused by higher levels of motivation. Because of this and to help gain a broader understanding of the teaching of metacognitive skills, interviews were conducted with the regular teacher of each group; this is reported in Chapter 7.

Chapter 7: Insights provided by teachers' interviews about how they support students with metacognitive strategies.

7.1 Introduction

This study was concerned with comparing the teaching styles that students of the three groups received from their regular teachers before the intervention. This could help better understand the pre-test scores of the three groups and the gains made by two of the groups in their PST scores (Chapter 5). This chapter focuses on the teachers' reports about the way they helped students with stoichiometry and so compliments the previous chapter which concerned the students' reports about metacognition and motivation. This chapter also provides information about the sort of teaching strategies that were used by the three teachers to help their students with stoichiometric problem-solving.

The investigation described here concerns teaching approaches that were used with the students in the three groups before the training sessions. Semi-structured interviews were chosen as a data collection instrument for this study because it allows informants to elaborate on their responses, thus giving the researcher an insight into the informants' thinking. Details of this data collection method are discussed in Chapter 3.

Two issues are considered in the interviews. First, the teachers were asked about their general approach to teaching stoichiometry. Second, follow up questions were directed at finding out if the teachers also taught metacognitive skills and if so, what teaching approaches they used. A third set of questions were also asked about the teaching strategies that could have influenced students' motivational orientation. This information was collected to see whether the instructional strategies that were

used by the teachers of the three groups were similar or different to those reported in previous research. The information was also collected to see whether these instructional strategies could help explain the pattern of findings about the MCAI and PST scores reported in Chapter 5, although it should be noted that the teacher of Group A (MSM) had only taught chemistry to his students for one term.

7.1.1 General teaching approach adopted by teachers of stoichiometry

In this section there is a review of the methods of teaching stoichiometry and the possible effects of different methods on metacognition. In general, teachers do not follow instructional methods that foster metacognitive learning (Kistner et al., 2010). In their study of German mathematics teachers, the authors found that teachers did not spend much time instructing students about effective methods of learning. Similarly, Leutwyler (2009) observed that the traditional curricula and instructional methods were not sufficiently equipped to promote metacognitive learning.

Research findings suggest that teachers of stoichiometry generally follow an algorithmic or symbolic approach when teaching stoichiometry (Gabel, 1999; Robinson, 2003). Both these approaches involve teaching students to follow a sequence of steps when solving numerical problems, and usually, these are the steps outlined in most textbooks of secondary school stoichiometry (Haidar and Naqabi, 2008).

Algorithmic or symbolic teaching is an approach where students are given a set of rules and formulas to follow in solving algorithmic problems. It involves limited reasoning and promotes rote learning (Gabel, 1999; Robinson, 2003). In contrast, the conceptual development approach is where the teacher builds a conceptual framework through defining key concepts and demonstrating how all concepts, ideas

and principles link up together (Haidar and Naqabi, 2008). For example, in stoichiometry the key conceptual framework consists of, but not limited to the mole, relative masses, balanced chemical equations, chemical symbols, and the law of the action of masses.

It has been argued that algorithmic or symbolic teaching techniques do not promote the development and use of metacognitive strategies by students, as students are simply taught rules to follow and are not allowed space to reflect on their learning. Furthermore, in general, current teaching practices in high school chemistry classrooms do not seem to focus on encouraging students to reflect on their thinking (Haidar and Naqabi, 2008; Robinson, 2003; Gabel, 1999).

7.1.2 Algorithmic and conceptual teaching approaches

Algorithmic or symbolic instruction promote memorising and rote learning, which in turn is likely to limit students' ability to reflect on the what, how and why of what they learn (Haidar and Naqabi, 2008). When students memorise facts without questioning them, they are not questioning their thought process and therefore they cannot develop their metacognition because rote learning takes place when learning does not occur at the conceptual level (Haidar and Naqabi, 2008; Cardellini, 2002).

An instructional approach that emphasises conceptual understanding usually challenges students to reflect upon their learning; and in so doing helps students to develop their metacognition (Robinson, 2003; Cardellini, 2002). It is reasonable to deduce that when this approach is applied in teaching stoichiometry, it allows students to develop an awareness of connections that exist across a number of basic concepts, ideas, rules and principles. When students see connections across related ideas and principles, they do not need to memorise formulas, rules or principles, instead they can derive them by applying their conceptual understanding (Robinson,

2003). For example, when students understand the law of conservation of mass or the law of action of masses, they are able to compute the masses of both reactants and products using the mole concept and reflect on the solutions; they do not have to memorise the formulas. Haidar and Naqabi (2008) argue that when students reflect on the solutions of their stoichiometry problems and at the same time question their learning, they avail to themselves an opportunity to develop their metacognition.

A learning environment which integrates stimulation of students' interest and active learning as well as collaborative learning and peer tutoring often promotes metacognitive thinking skills (Ellis et al., 2014). Working in collaborative groups or pairs allows students an opportunity to explain to each other the steps they followed to solve the problem and the reason they chose the strategy they followed. Such opportunities where peers explain to each other strategies for solving problem tasks allow strategy modelling to take place which is also part of explicit instruction which promotes metacognitive awareness (Sharlach, 2008).

To summarise: Research findings suggest that in general teachers of stoichiometry adopt an algorithmic approach in lessons about stoichiometry (Haidar and Naqabi, 2008; Gabel, 1999). Teaching students stoichiometry using an algorithmic approach is unlikely to promote the development of metacognitive skills, while a conceptual developmental approach is likely to help students to reflect on their learning thereby availing to themselves opportunities to develop their metacognition (Haidar and Naqabi, 2008; Robinson, 2003; Cardellini, 2002). Thus, discovering the instructional methods used by the three teachers could help to understand the metacognitive abilities shown by the students in the pre-test assessments, provide information about the instructional methods used by the teachers and might also give insights into the pattern of findings at the post-test.

7.1.3 Motivation strategies

In Chapter 6, a link between motivation and metacognitive awareness was discussed. Three components of motivation were discussed; expectancy component, value component and affective component. The expectancy component concerns the student's ability to answer the question 'Can I do this task?' (Pintrich and De Groot, 1990). The various attributes of the expectancy component of motivation are linked to the learner's metacognition (Ambrose, Bridges, DiPietro, Lovett, and Norman, 2010; Pintrich and De Groot, 1990). The learning environment and how teachers structure and deliver the learning activities can have an impact on students' expectancy component of motivation (Ambrose et al., 2010). For example, a teacher who starts by giving students easy tasks to build their confidence is likely to have a positive impact on the students' expectancy component of motivation as the task increases in difficulty (Efklides, 2011; Ambrose et al., 2010).

The value component of motivation concerns the student's perceived value in carrying out the learning task. In other words, the learner must answer the question; 'why I am doing this task?' (Pintrich and De Groot, 1990). There often is increased metacognitive activity and engagement with the task when the student is motivated to carry out the learning task (Ames and Archer, 1988; Nolen, 1988; Paris and Oka, 1986). The teacher can play an important role in shaping the students' value component of motivation by making a difficult learning task more interesting or manageable by using different strategies. For example, the teacher could pair up students to facilitate reciprocal or peer tutoring.

The affective component of motivation has to do with how students feel about the learning task. In other words, it's about a learner asking 'How do I feel about this task?' (Pintrich and De Groot, 1990). As reported in Chapter 6, generally students

believe that stoichiometry is a difficult area of chemistry and this subject belief can result in a dislike of stoichiometry (Efklides et al., 1999; Schwarz, 2010). Again, as already observed, teaching strategies can play a significant role in helping students develop a positive affective component of their motivational orientation. As a result, discovering more about the way that the teachers of the three groups increased the motivation of their students could provide a broader context to the research and might also help to provide explanations for the findings reported in Chapter 5.

Research Questions

The overall aim of carrying out the interviews with the teachers of the three groups was to obtain a better understanding of the usual instructional strategies that they used when teaching stoichiometry (i.e. the strategies they used before the research intervention). The first reason for collecting this information was to see whether the similarities and differences in teaching could help to explain the findings reported in Chapter 5. The second reason for collecting this information was to better understand the context of the research and whether the teachers used instructional strategies that were similar to those that have been previously reported. Consequently, the three research questions concern the teaching prior to the intervention:

1. What instructional strategies did the teachers of the three groups use to help students with stoichiometry?
2. What instructional strategies did the teachers of the three groups use to help develop their students' metacognitive knowledge and skills?
3. What instructional strategies did the teachers of the three groups use to motivate students when teaching stoichiometry?

7.2 Method

7.2.1 Participants

Three teachers were interviewed. The teacher of Group A is referred to as teacher A and that of Group B as teacher B while that of Group C is referred to as teacher C. The usual chemistry teachers of groups A, B and C taught these groups in the research study, although the teacher of Group A had only been carrying out these duties for a term. It was not possible to find different teachers to teach the groups, although this would have been an advantage.

7.2.2 Procedure

Interviews were conducted in a quiet place chosen by each teacher. For example, teacher A and B had access to a quiet office on their respective campuses, while teacher C preferred to be interviewed in her laboratory. The interviews lasted between 20-30 minutes depending on how engaging the interviewee was during the interview. All interviews were carried out using similar questions (see Appendix 5). The opening question was always *Can you just talk me through how you teach stoichiometry, what's your approach and how do you develop the topic.* Follow up questions depended on the response given by the interviewee and these along with other independent questions were used to build up the conversation.

7.3 Results

7.3.1 Transcription

Appendix 21 shows the questions, responses/comments given by each teacher. Where there was no response it could be an indication that the teacher did not make a comment about that particular theme and not necessarily that they did not answer the question.

7.3.2 Analysis

The teachers' interviews were transcribed and analysed according to the questions asked which followed preselected themes, thus thematic analysis was adopted for analysing data as described in chapter 6. The questions asked were concerned with how teachers generally taught stoichiometry and whether these approaches reflected metacognitive teaching approaches. The data was coded in a similar way as described in chapter 6.

In the next section, a summary is provided of the responses of the three teachers in relation to the questions being addressed in this investigation.

7.3.3 What instructional strategies were used by the teachers of the three groups to help their students learn about stoichiometry?

When teachers were asked about their general approach to teaching stoichiometry, their responses varied both in breadth and depth, possibly reflecting their differing levels of experience as teachers of chemistry. There were a number of similarities between Teachers A and B, with Teacher C adopting a number of different instructional strategies to the others. While both teachers of Groups A and B reported that they started by introducing formulas of compounds and elements, followed by calculations, the teacher of Group C, the control group reported that she started by

reviewing the fundamental concepts and ideas of chemistry covered in the first two years of secondary school. For example, she said she would make sure that students remembered states of matter and formation of solutions of compounds from which she would derive conceptual frameworks that are operational in learning stoichiometry. In other words, she took the conceptual development approach while the other teachers took the algorithmic or symbolic approach to teaching stoichiometry.

All teachers reported that they taught students the use of formulas, but they differed on how these formulas were taught. As stated above, the Group C teacher used conceptual development to introduce formula while the other two teachers 'gave' formulas to students and asked the students to 'learn' them. Group B teacher provided elaborate algorithmic steps (shown in Appendix 21) which he said he advised his students to follow when solving stoichiometry problems. The Group C teacher simply emphasized the need to know the chemical formula of compounds and chemical symbols of elements. The main difference reported by the teachers of the three groups was how they taught fundamental concepts of stoichiometry. Teachers of Group A and B focussed on teaching knowledge of procedure (algorithm) while the teacher of Group C focussed on teaching students to understand the procedures. It can be concluded that the teachers of the three groups used different teaching strategies for stoichiometry.

7.3.4 What instructional strategies did the teachers of the three groups use to help their students use metacognitive strategies?

When teachers were asked if they emphasized conceptual understanding while teaching stoichiometry they all responded that they did, but again there were differences in the depth of their responses, with most of the differences between Teacher C and the other two teachers. The teacher of Group A spoke of the

importance of teaching conceptual understanding but did not state that he actually did it with his class. For example he said *'If the teacher fails to teach the basic concepts of stoichiometry then it becomes difficult for students understand the topic.'* The teacher of Group B did indicate superficially that *'.... normally when I teach stoichiometry, I start by teaching the simple concepts and then go step by step to more complex concepts and processes'*. This is in contrast to the detailed response given by Group C teacher who gave solid examples of how she develops stoichiometry concepts in sequence to allow students to develop conceptual change. From the teachers' responses, it is clear that they understood the importance of conceptual understanding, but there is little evidence that teachers A and B actually incorporated these approaches in their teaching to promote conceptual understanding.

All teachers reported that they asked students to read a stoichiometry question and extract relevant information. This indicates that teachers taught their students planning strategies for solving problems in stoichiometry. The Group B teacher elaborated on his response by saying that he tells his students to extract all *numerical information given in the question and then decide which equation to use*. A similar view was shared by the Group C teacher who stated that *'I always tell them that when they get a question (stoichiometry) they should underline the relevant information given in the question and also underline what has been asked to find'*. The teacher of Group A expressed similar views when he said *I tell them that they must read the question first and find out what information is given, identify the pieces of information provided which are required for solving the problem*.

All teachers reported that they modelled problem-solving on the board before asking students to attempt solving stoichiometry problems following an algorithmic sequential approach. However, their responses differed when they were asked

whether they encouraged their students to pause and ask themselves whether they were using the correct formula or method while solving a problem task (these are metacognitive skills. see Appendix 1). Teacher A responded that he advised students to review their work when they have completed it. A similar response was given by teacher B while teacher C responded that she does so but in a whole class problem-solving activity. She reported that when she asks a student to solve a problem from the whiteboard, she asks the class to follow, reflecting on the correctness of the procedure being used by the student. However, she did not say that she deliberately encouraged her students to *reflect* on their own work while solving problem tasks on their own.

While all teachers reported that they allowed students to consult each other, the teacher or their textbooks while solving stoichiometry problems, teachers A and B stated that they did not necessarily tell students do so. Teacher C said that she organised her students in groups where she combines students with different ability levels. When asked why she did this, she responded that she did so to encourage collaborative learning so that more able students could help less able. She further stated that *working alone can sometimes be frightening and if they are working individually, confidence levels may be low because they think, 'am I doing the right thing or no'. But if they consult each other they can have a discussion and have a joint effort in completing the problem task.* The teacher also justified her strategy for grouping students saying that *there are opportunities for peer tutoring when students of mixed abilities work together.*

When students learn from each other it's less intimidating to ask each other when they don't understand than if they were to ask the teacher, because the student might think that they are the only one not getting it and they have to ask the teacher when

the whole class is quiet and listening to them asking for help from the teacher. This approach is not reported by the other teachers and this seems to mark the fundamental difference in how the three groups received regular instruction in chemistry in general. While it can be concluded that all three teachers did use metacognitive strategies to some extent, there is sufficient evidence to suggest that the teacher of Group C used more metacognitive teaching strategies compared to the teachers of the experimental Groups A and B.

7.3.5 What instructional strategies did the teachers of the three groups use to motivate students when teaching stoichiometry?

The teachers' responses on how they facilitated motivation were varied. Teacher A spoke of the importance of providing motivation but did not specifically say how he motivated his students during stoichiometry lessons for example he said *Motivation is important not only in chemistry but across all subjects. It is through the interest, the attitude that the student has that will determine whether the students understand the subject or topic that they are learning. So it's not only limited to chemistry or stoichiometry alone. I noticed that motivation matters to other subjects as well. If students are to perform well, they need to love what they are learning and this will enable them to actively participate in learning the subject.* Teacher B did describe what he believed kept his students motivated in his stoichiometry lessons. He said *I start by giving students simple problem tasks which they do not struggle with. This helps to build their confidence which allows them to transit to more challenging problem tasks.* He also added *I give them achievement targets which they should achieve and when they achieve these targets we celebrate and compliment those who achieve their targets. The targets are however differentiated so that each student is able to work at their own level.*

Teacher C gave a much more detailed and amplified response on motivation. In her comments she said *I wouldn't say I do anything special (to motivate), but it's simply giving them encouragement. It's about showing care and concern for students. For example, one of my students on the group that you interviewed struggled with her English and I had to tell her that unless she improved on her English, understanding chemistry was going to be difficult for her. She took my advice on board and now she has made tremendous improvement and she is now quite confident.* Teacher C also added *I also have a good knowledge of my students' individual circumstances for example if they are orphaned or maybe they are having a difficult time at home or at school. I show them that I am interested and concerned about them as students.*

In conclusion, the analyses show that the teachers had differences in how they motivated their students. Although there are differences in the strategies used by the teachers, this does not appear to have affected the students' motivational orientation; this agrees with what was reported in Chapter 6.

7.4 Discussion

This study focussed on finding out what instructional approaches were used to teach stoichiometry and if there was a link between the teaching approaches and the students' metacognitive awareness and PST scores. The study was also concerned with finding out if the teachers of the three groups used similar strategies to motivate their students when teaching stoichiometry.

The analyses of the teachers' interviews indicate that there were similarities and differences in the way the three teachers taught stoichiometry. The analyses show that teachers of the intervention groups predominantly followed an algorithmic or symbolic teaching approach, while the control group teacher reported using a

combination of teaching strategies which included metacognitive teaching strategies. The control group teacher also reported using the conceptual development approach, collaborative learning in groups or pairs and peer tutoring. The following section discusses the teachers' instructional approaches and how they could have impacted the students' metacognitive awareness and use.

7.4.1 Did the teachers of the three groups use the similar strategies to teach stoichiometry and what were these strategies?

The teachers of the intervention groups reported that they predominantly used algorithmic approach, and this is consistent with findings reported in previous research (Haidar and Naqabi, 2008; Robinson 2003; Gabel, 1999). Haidar and Naqabi argue that limiting the teaching of stoichiometry to simply explaining the steps and rules to be followed does not help students to develop conceptual understanding and it is believed that this approach encourages students to resort to rote learning, which in turn is unlikely to develop their metacognitive awareness (Cardellini, 2002; Gabel, 1999).

Unlike the teachers of Group A and B, the teacher of Group C reported using less of algorithmic teaching and more of conceptual development in her teaching of stoichiometry. For example, she said that she made sure that the *students need to understand the concepts because if they don't understand the concepts they will memorise and if they simply memorise without understanding when confronted with a problem they won't even understand what the question requires them to do.* Consequently, it would appear the instructional strategies (algorithmic and conceptual) used by the three teachers were similar to forms of teaching that have been described in previous research, however, the teacher C used more conceptual approaches.

7.4.2 Did all the teachers of the three groups use metacognitive strategies when teaching stoichiometry and what were these strategies?

The analyses showed that all three teachers taught metacognitive strategies to some extent. For example, all teachers reported that they told their students to read a question and identify what the question requires them to do, extract relevant information and select an appropriate strategy. This shows that the teachers taught their students metacognitive skill of planning. The teachers also reported that they trained their students to review their work. In other words, they taught their students about evaluation.

The analyses showed that the extent to which the teachers taught these skills varied between them, with the Group C teacher demonstrating a deeper knowledge of metacognitive teaching strategies. For example, she reported that she approached teaching stoichiometry by reviewing the fundamental concepts and ideas of chemistry covered in the first two years of secondary school and would make sure that students remembered states of matter and formation of solutions of compounds from which she would derive conceptual frameworks that are essential in learning stoichiometry. Conceptual understanding is considered to be the most important determining factor in solving stoichiometry problems as reported by BouJaoude and Barakat (2003) in their study where they found that students who exhibited more conceptual thinking were also the most successful problem solvers. The authors also found that students who were less conceptual in their thinking had the tendency to predominantly use algorithms in problem-solving while conceptual thinkers made use of conceptual reasoning along with algorithms. There is a positive correlation between conceptual understanding and successful problem-solving in stoichiometry (BouJaoude and Barakat, 2003).

When students engage in conceptual thinking, they are able to *reflect* on their thinking as they solve stoichiometry problems, thus students develop their metacognitive awareness and use (Haidar and Naqabi, 2008). The teacher of Group C also reported that she would ask her students as a group to reflect on a problem-solving sequence as one of her students solves a stoichiometry problem on the whiteboard. The word *reflect*, is used in the present context to make reference to the process of thinking about one's thinking process (metacognition) in learning and task execution. This term is also used synonymously with the term self-reflection (Zimmerman, 1989). Self-reflection is considered to play pivotal role in the achievement of self-regulated learning (Zimmerman, 2000).

Teacher B gave an elaborate list of the rules and steps for students to follow when solving stoichiometry. For example, he said I normally *start with simple calculations involving for example empirical formula, percentage composition, relative formula mass etc. These are just simple calculations which are procedural. In other words they are algorithmic there is little reasoning involved.* This teaching approach which is algorithmic does not promote self-reflection and as result students cannot develop their metacognitive skills awareness and use (Haider and Naqabi, 2008; Robinson, 2003; Gabel, 1999).

Although all teachers did engage in algorithmic teaching, the control group teacher reported that she started the teaching of stoichiometry from basic concepts such as states of matter (i.e. solids, liquids and gases) and worked through the rest of the fundamental concepts and ideas. She came across as having taught students to understand the process of problem-solving, while the other two teachers gave the procedure to the students to learn it. It can be argued that when teaching involves developing conceptual understanding, it provides opportunities for students, to reflect

upon their learning, so that they can see connections between various conceptual building blocks, and they can derive formulas from definitions. Thus, there is no need for students to memorise formulas or laws. The understanding of the law of action of masses for example, can be developed from the mole concept and balancing chemical equations. This way, students develop their metacognitive skills awareness because they have opportunities to reflect on and question their thinking as they solve problem tasks (Elis et al., 2014; Haider and Naqabi, 2008; Robinson 2003; Gabel, 1999).

The control group teacher also reported organising her class into pairs and groups for both collaborative learning and peer tutoring. She organised the groups by mixing ability levels of students. When students work in collaborative groups or pairs that involve peer tutoring as described by the Group C teacher, they avail to themselves opportunities to describe and explain to each other how they solve stoichiometry problems (Ellis et al., 2014). Students engaged in collaborative work often experience reciprocal explanation, and this can be considered to be an extension of self-explanation, and it is reported in previous studies that this allows students to develop their metacognitive awareness as students practice to self-monitor and self-evaluate their input during collaborative problem-solving activities (Scharlach, 2008).

To summarise, all the teachers used metacognitive teaching strategies to some extent, but the Group C teacher used a variety of approaches that are likely to have enhanced students' metacognitive awareness and use.

7.4.3 Did all the teachers of the three groups use similar strategies to motivate students when teaching stoichiometry?

The teachers reported using different strategies to influence their students' motivational orientation. Teacher A for example demonstrated an understanding of the importance of motivation when he said *It is through the interest and the attitude that the student has that will determine whether the student understands the subject or topic that they are learning*. He went on to say that *If students are to perform well, they need to love what they are learning and this will enable them to actively participate in learning the subject*. However, teacher A did not give examples of strategies that he used. His statements indicate an appreciation of some of the attributes of motivational components such as the value component and the affective component of motivation. For example students who show positive attitude and an interest in the learning task are likely to persist on the task despite the challenge (Ambrose et al., 2010; Paris and Oka, 1986; Schunk, 1985).

Teacher B described how he motivated his students during the lesson; *I start by giving students simple problem tasks which they do not struggle with. This helps to build their confidence which allows them to transit to more challenging problem tasks*. He also added *I give them achievement targets which they should complete and when they achieve these targets we celebrate and compliment those who achieve their targets*. The targets are however differentiated so that each student is able to work at their own level. Building confidence helps students develop the expectancy component of their motivation because they develop a 'can do' attitude. Giving students differentiated achievement targets helps them to progress according to their ability level and this allows them to have more interest in the learning task thus keeping them motivated (Efklides, 2011; Ambrose et al., 2010).

Teacher C reported using different strategies and she gave an example of a girl who she said struggled with stoichiometry because her poor English was poor. She reported that she encouraged the girl to improve on her English and eventually the girl improved her achievement in stoichiometry. When students feel encouraged, this is likely to boost confidence building which in turn leads to improved motivation (Efklides, 2011). A discouraged learner is likely to be a demotivated learner. Teacher C also said *I also have a good knowledge of my students' individual circumstances for example if they are orphaned or maybe they are having a difficult time at home or at school. I show them that I am interested and concerned about them as students.* Understanding students' personal circumstances which are likely to affect their learning can help students to be motivated to learn because they feel cared for by the teacher. This show of concern may have a positive influence on the expectancy and value components of students' motivation.

In conclusion, although there are clear differences in teachers' motivation strategies, the students' self-reported motivational orientation across the three groups did not appear to differ as was discussed in Chapter 6. As a result, it is possible that individual differences between students may be more important in determining their motivation, rather than the strategies used by the teacher. It also is the case that the students of Group of C were preparing for their external examinations and as a result, most were likely to be motivated to learn about problem-solving in chemistry.

7.4.4 Relations between Teaching Strategies with Student Metacognition and PST scores.

It seems likely that the algorithmic and conceptual teaching strategies would have the biggest impact on *pre-test* MCAI and PST scores, so it is useful to discuss whether this was the case. In Chapter 5, at pre-test it was found that Group A (MSM) had the lowest MCAI scores and these were significantly lower than those of Groups B and C. This would suggest that students in Group A had the lowest levels of metacognitive skills before they started the intervention and this would suggest that their teacher was the one who was least effective in teaching these skills. However, the interviews with the teachers suggest that there was little difference in the teaching strategies of the teachers of Group A and B who both used more of the algorithmic approach, and therefore might be expected to be less effective in developing metacognitive skills than the teacher of Group C who used the conceptual approach. Group A had only been taught by their current teacher for one term and so there are uncertainties about what had happened prior to this and the impact on MCAI pre-test scores. Thus, there are uncertainties about why Group A had significantly lower MCAI scores at pre-test.

In chapter 5 it was found that at pre-test Group A (MSM) had the highest PST scores and these were significantly higher than those of Group B. This would suggest that students in this group had the highest levels of stoichiometric abilities at the beginning of the intervention and their teacher was the one who was most effective in teaching these abilities. In contrast, Group B (MSF) was the group with the lowest PST scores and this would suggest that the teacher of these students was the least effective in promoting stoichiometry abilities. However, the interview answers of the teachers of Groups A and B suggested that they broadly used similar strategies to teach stoichiometry. Again, this discrepancy between the teachers' reports and the pre-test

PST scores could be explained by the fact that Teacher A had only one term with his students. Another possibility is that there could have been differences in ability between the groups. Thus, there are still uncertainties about why Group A had the highest PST scores at pre-test. In addition, the Teacher of Group C, appeared to be the most effective of the three teachers in supporting the chemistry skills of her students. However, the pre-test PST scores of her students were approximately midway between those of Groups A and B. Thus, these findings point to a lack of correspondence between the use of teaching strategies and the students' PST scores.

In chapter 5 it was also reported that Group B (MSF) and Group C (control) made significant improvements in their PST scores. Given the preceding discussion these findings might be due to the MSF being an effective intervention to develop stoichiometry abilities, and the progress might be due to the control group already having good metacognitive abilities which allowed them to make the most gains from their extra experience with chemistry problems. It is also possible that the teacher of Group C was a particularly effective teacher and as a result, during the intervention she continued to provide a very effective learning experience for her students with the result that the control group has a significant increase in their PST scores.

7.5 Summary

In general teachers of stoichiometry follow algorithmic or symbolic teaching approach. This approach does not usually promote the development of metacognitive skills awareness as students do not have opportunities to question their thinking. It is more of a prescriptive kind of teaching where students learn without necessarily understanding the underlying concepts and as result students tend to memorise steps and rules to follow when solving stoichiometry problems. It was observed that this was the teaching approach predominantly followed by the teachers of the

intervention groups while the teacher of the control group used a mix of different teaching approaches which included collaboration, peer tutoring, and conceptual development.

The control group teacher who taught her students by starting from basic concepts to build up a conceptual framework in stoichiometry may have helped students to develop conceptual understanding of stoichiometry by reflecting on their thinking as they solve stoichiometry problems (Haidar and Naqabi, 2008; Cardellini, 2002). Her students learned in collaborative groups or pairs; this also gave them opportunities to develop their metacognitive awareness (Ellis et al., 2014; Scharlach, 2008). It is possible that the control group students developed metacognitive skills awareness more because the teacher taught them metacognitive strategies.

One cannot be sure why there were no statistically significant differences in MCAI scores between the control Group and both intervention groups at pre-test. However, it is possible that the control group teacher had supported her students using metacognitive strategies and as a result they continued to improve on their MS awareness and academic achievement during the intervention. It is also possible that this teacher continued to encourage metacognitive strategies during the intervention and this resulted in improvement in PST scores between pre- and post-test. The low MCAI pre-test scores and high PST scores of the MSM Group could possibly be explained by individual students' characteristics as a different teacher taught them stoichiometry prior to the intervention.

The teachers of the three groups used different approaches to motivate their students, although the students did not report differences in their motivational orientation as discussed in Chapter 6. The teacher of Group C appears to have used better strategies for motivation compared to the other two teachers although this

does not appear to have resulted in higher levels of motivation in the Group C students. The next chapter brings the findings from the four studies together and discusses the contribution made by these findings to our understanding of metacognition and learning, and the implications for practice. In addition to discussing limitations of this research, the chapter also concerns a discussion on the importance of multi-method approach in researching metacognition.

Chapter 8: Discussion

8.1 Introduction

The aim of this thesis was to find out if instructional interventions which teach metacognitive strategies during problem-solving activities in stoichiometry could increase achievement and metacognitive skills awareness and use in secondary school students. Also investigated in this thesis were the students' perceptions of their motivational orientation together with their metacognitive skills awareness and use; and the teachers' perceptions of how they teach stoichiometry.

Each of the results chapters in the thesis addressed a specific set of questions. In the first study (Chapter 4) there was an investigation of whether an explicit metacognitive skills instructional method could help students improve their MS awareness and achievement in stoichiometry; in the next chapter (Chapter 5), the investigation concerned whether two explicit metacognitive instructional methods; MSF and MSM, increased metacognitive awareness and use, and achievement in stoichiometry during problem-solving.

The following chapter (Chapter 6) concerned similarities/differences in students' self-reported MS awareness and use, their general level of MS awareness and motivational orientation during problem-solving tasks in stoichiometry. Then the last research chapter (Chapter 7) considered whether the teachers of the three conditions used similar or different instructional approaches to teach stoichiometry and to motivate their students and also whether their teaching approaches involved the use of metacognitive instructional methods. In this chapter, there is also a consideration of broader issues about metacognition and the relevance of the findings to practitioners.

Sections 8.2-8.5 focus on the findings from the four studies. Section 8.6 discusses the overall conclusions drawn from the four studies. Section 8.7 discusses implications of the findings for teaching and learning and section 8.8 is concerned with the limitation of this research while in section 8.9 suggestions for further research are discussed. The chapter concludes section 8.10 which summarises and synthesises the findings from the four studies and how they made a contribution to our understanding of metacognition in teaching and learning.

8.2 Study 1: The effect of instructional intervention on students' metacognitive skills and achievement during problem solving in IGCSE stoichiometry.

The analyses showed that in the experimental group (MSF) there was no statistically significant increase in the students' MCAI scores. However, there was a statistically significant increase in PST scores between the pre-test and post-test for the intervention group suggesting that the MSF training had resulted in an improvement in solving chemistry problems. There was no statistically significant difference in the pre- and post-test mean scores of MCAI and PST for the control group.

The findings are consistent with previous research from similar studies where students in the experimental group had a significant improvement in their chemistry scores compared to a control group as a result of metacognitive training although different instructional approaches were used (Zepeda et al., 2015; Pennequin et al., 2010; Sandi-Urena et al., 2011; Swanson, 1990). The findings are also consistent with other research which has shown a decline in MCAI scores from pre-test to post-test during an intervention (Chapter 4). This decline in the actual scores has been interpreted as an improvement in metacognitive awareness which resulted from more realistic ratings of metacognition (Sandi-Urena and Cooper, 2009). Consequently, the results support the claim made by some researchers (Rickey and Stacey, 2000; Schraw et al.,

2006; Sandi-Urena and Cooper, 2009) that teaching metacognitive skills improves students' problem-solving skills. The findings from this study supported two arguments; first, that metacognitive skills can be changed through classroom instruction and secondly that there is relational link between metacognitive skilfulness and achievement in solving stoichiometry problems.

8.3 Study 2: Comparing instructional effectiveness of MSF and MSM in developing students' metacognitive awareness and achievement during problem solving in IGCSE stoichiometry

The aim of this study was to investigate whether two metacognitive instructional approaches (MSF and MSM) improved students' achievement scores and their metacognitive awareness and use during problem-solving in stoichiometry. Metacognitive skills modelling (MSM), involved the teacher demonstrating how to solve stoichiometric problems by making their metacognitive strategies 'visible' to the students (Ellis et al., 2014; Archer and Hughes, 2011). In other words, the teacher demonstrated how to apply the components of metacognitive skills in problem-solving. MSF was expected to show a greater impact on the students' metacognitive awareness because it is a more explicit method and previous research suggests the existence of link between explicit metacognitive instructional methods and metacognitive awareness (Ellis et al., 2014; Archer and Hughes, 2011).

The results showed that there was no significant overall improvement of students' MCAI scores over the period of the intervention. However, there were differences between groups, but no significant interaction, showing that effects did not vary across time and group.

These findings suggest that the two instructional methods did not make a difference in the students' metacognitive awareness. Therefore, the results suggest that the

extent to which a metacognitive instructional method is explicit may not necessarily have a bearing on the students' development of metacognitive skills awareness. This finding differs from previous research where it has been suggested that an explicit metacognitive instructional method helps students to enhance their metacognitive skills (Ellis et al., 2014; Sharlach, 2008). Although not statistically significant, the decrease in MCAI score over time for the MSF and MSM groups is consistent with previous findings and could be an indicator of improvement in metacognitive awareness (Sandi-Urena and Cooper, 2009).

The MSF and control groups in Study 2 showed a significant improvement in achievement scores. The MSF group experienced the highest improvement in achievement scores; there was no significant increase for the MSM group. This suggests that the MSF intervention was more effective than the one administered to the MSM group. This was consistent with the prediction made about the benefits of explicit metacognitive instructional methods (Ellis et al., 2014; Archer and Hughes, 2011). However, surprisingly, the control group scores increased quite substantially. This could be due to a number of reasons. For example, the majority of the students could have been bright students as this was not controlled, or the teacher was a more effective in teaching stoichiometry. It was also reported that these students were preparing for public exams which included chemistry, therefore they might have been more committed to the problem-solving tasks given during lessons, thus making them improve on their achievement. This required further inquiry reported in Chapters 6 and 7.

To investigate the relationships between the MCAI and PST scores correlations were calculated for each group at pre-test and post-test. This involved firstly, an examination of the correlations between the chemistry achievement scores in relation

to the students' overall metacognitive skills awareness MCAI scores), and secondly an examination of the correlations between the four metacognitive skills components and the chemistry achievement scores (PSTs).

There were weak to moderate non-significant correlations between the MCAI and PSTs scores. This shows that it is unlikely that these relations would occur in another independent study. These findings are different from what has been reported in previous studies where a direct relationship between metacognitive awareness and achievement has been suggested, i.e. the higher the level of metacognitive skills awareness the higher the achievement (Zepeda et al., 2015; Cook et al., 2013; Pennequin et al., 2010; Sandi-Urena and Cooper, 2009; Schraw et al., 2006; Rickey and Stacy, 2000; Swanson, 1990). However, these studies did not use the same research design as the one used in this study. In addition, these studies did not involve computation of correlation.

In addition, finer grained analysis of the metacognitive skills components (Planning, Monitoring, Control, and Evaluation) was carried out to investigate which component(s) had the highest correlations with metacognition or problem-solving.

There was very little evidence that one or more of the components of the MS were related to the PST scores. This supports the previous analysis using total MCAI scores and suggests there is little or no relationship between how students rate their awareness and use of MS components in relation to their problem-solving skills as assessed by their PST scores. Thus, the analyses showed that the correlations between total MCAI and PST were weak and inconsistent both across the groups and across time.

8.4 Study 3: Assessing similarities/differences of metacognitive skills and motivation of students of stoichiometry

This study concerned the self-perceptions of MS awareness and use by some of the students who took part in the research described in Chapter 5, where students in the experimental and control groups had similar MCAI and PST scores at post-test. The aim of this research was to better understand the reasons for the similarities in MCAI scores at post-test between the experimental groups and the control group using semi-structured group interviews (Appendix 4). Participants responded to questions about their awareness and knowledge of strategies related to the use of the four MS components; planning, monitoring, control and evaluation, as well as questions about their motivation.

Three issues were addressed in the analyses: whether there were similarities in metacognitive skills across the three groups as no difference had been found in MCAI and PST scores at post-test; whether there were similarities in the *level* of MS skills awareness and use across the groups; and whether the students had similar or different motivation levels which could also help to explain the lack of significant differences between groups in the MCAI and PST scores at post-test.

More specifically, students' responses about their awareness and use of MS were expected to confirm or challenge the results obtained from the students' MCAI self-report. It was considered that the reasons for the control group's increase in MS awareness and use could perhaps be understood by speaking to the students from that group and then comparing their responses to those given by the intervention groups. It was also suggested that motivational orientation might have been a factor influencing the control group's PSTs scores, therefore this was also investigated. High

motivational orientation has a positive influence on task performance (e.g., Ames and Archer, 1988; Nolen, 1988).

All participants from the three groups reported similar metacognitive awareness with respect to the planning component. This is consistent with previous research where students of stoichiometry generally exhibited heightened awareness and use of the MS planning component because teachers of stoichiometry tend to concentrate on teaching students planning skills (e.g. Haidar and Naqabi, 2008). This also agrees with findings reported in Chapter 5.

The analyses showed that there were differences and similarities with respect to the monitoring component of MS across the three groups. The analyses showed that MSF group and control group answered more questions affirmatively, indicating a higher level of MS monitoring skills compared to the MSM group. Previous research on monitoring skills indicates that students tend to develop better monitoring or self-checking skills in areas that involve calculations such as those encountered in stoichiometry because they are generally encouraged to review their calculations to check for accuracy (e.g. Cohors-Fresenborg et al., 2010; Haidar and Naqabi, 2008).

The MSM group's depth of discussion and responses to questions about the monitoring strategies revealed a low level of metacognitive skills awareness and use compared to MSF group and control group. This is consistent with the findings from Chapter 5 where MSF and the control group had significantly higher MCAI scores than the MSM group (there was an overall main effect of group across pre- and post-test, this effect was found to be significant at pre-test, although the effect failed to reach significance at post-test).

There were differences between the three groups' answers about the control component. The analyses showed that MSM group reported a lower level of MS awareness and use compared to MSF and control group, while the MSF group and the control group reported similar levels. Again, this is consistent with the group differences involving the MCAI reported in Chapter 5. Although there were more students from the control group reporting the use of evaluation strategies than there were from intervention groups, there were no differences in the responses given by the students from the three groups, showing that the students' self-reported metacognitive skills awareness was similar across the groups with respect to this component.

A positive relationship between metacognitive skills awareness and achievement is only likely to exist if metacognitive skills awareness co-exists with metacognitive skills use (Cohors-Fresenborg et al., 2010). The interviews showed a connection between the levels of MS awareness and use with achievement, something not captured by the quantitative data. The results from the students' interviews provided an important insight into their perception of how they used their metacognitive skills, something which the quantitative data failed to reveal. The quantitative data failed to show a correlation between achievement and metacognitive awareness and use while the interviews seem to suggest this. The interviews provided students with an opportunity to elaborate on their responses, something that is not available when they are completing a self-report inventory such as the MCAI (Berg, 2007; Kvale, 2003; Morgan, 1996).

The responses given by the participants across the three conditions showed some differences and similarities in students' motivational orientation but overall, the students across the three groups provided similar and positive responses with regard to the affective, expectancy and value component of their motivational orientation.

As all the groups reported similar levels of motivation this suggests that motivational orientation was not a factor in the anomalies observed for the control group in Study 2. This is intriguing because one would have expected lower motivational orientation for the MSM group given that it is suggested that there is a link between achievement and motivational orientation (Pintrich and De Groot, 1990; Ames and Archer, 1988; Nolen, 1988).

The group interviews provided an effective way of gathering feedback on how the students used metacognitive strategies to solve stoichiometry problems and consequently, an opportunity to confirm or challenge findings from the previous experimental study (Chapter 5; Study 2) was availed. The answers provided by students about the components of MS revealed an agreement with group differences in the overall MCAI scores. The components of MCAI have not been previously investigated and it is an interesting development in the study of metacognitive skills. However, this study does not provide answers to why there were similarities in MS awareness and use between the control and the experimental groups; and a lack of the effect of the interventions on MS awareness and use as assessed by MCAI.

8.5 Study 4: Insights provided by teachers' interviews about how they support students with metacognitive strategies

In Study 3, it was reported that there were similarities in students' motivational orientation and MS awareness across the three groups. The analyses of the results from Study 3 partly explained the findings from Study 2. However, there were still uncertainties about the findings from Study 2, in particular the reasons for the control group showing an improvement.

Study 4 focused on the teachers' reports about the way they helped students with stoichiometry and, whether the teacher of the control group could have helped the

students' metacognition during the intervention and in this way helped them compensate for lack of intervention. Data was collected by means of semi-structured interviews.

8.5.1 Did the teachers of the three groups use the similar strategies to teach stoichiometry?

When teachers were asked about their general approach to teaching stoichiometry, their responses varied. There were similarities between the MSM and MSF teachers, with the control group teacher reporting the use of different instructional strategies. For example, while both MSM and MSF teachers reported that they started by introducing formulas of compounds and elements, followed by calculations, the teacher of control group, reported that she started by reviewing the fundamental concepts and ideas of chemistry covered in the first two years of secondary school. Thus, the Group C teacher used conceptual development to introduce formula while the other two teachers 'gave' formulas to students and asked the students to 'learn' them.

All the teachers reported using an algorithmic approach to teach stoichiometry, and this is consistent with previous research (Haidar and Naqabi, 2008; Robinson, 2003; Gabel, 1999). It is suggested that this approach does not promote conceptual understanding, and it is believed that it encourages students to resort to rote learning, which in turn is unlikely to develop their metacognitive awareness (Cardellini, 2002; Gabel, 1999). Unlike the teachers of MSM group and MSF group, the teacher of the control group reported using less of algorithmic teaching and more of conceptual development.

The analyses showed that all three teachers taught metacognitive strategies to some extent. For example, all teachers reported that they told their students to read a

question and identify what the question requires them to do, extract relevant information and select an appropriate strategy to solve the problem (i.e. planning). The teachers also reported that they trained their students to review their work after completing the problem task (i.e. evaluation).

However, the group C teacher appeared to demonstrate better knowledge of metacognitive teaching strategies than the other teachers. For example, she reported she would make sure that students remembered states of matter and formation of solutions of compounds from which she would derive conceptual frameworks required in the learning of stoichiometry. Conceptual understanding is considered to be the most important determining factor in solving stoichiometry problems (e.g. Naqabi and Haidar, 2008; BouJaoude and Barakat, 2003). There is a positive correlation between conceptual understanding and successful problem-solving in stoichiometry (Ellis et al., 2014; Haider and Naqabi 2008; BouJaoude & Barakat, 2003).

To conclude, all the teachers used metacognitive teaching strategies to some extent, but the Group C teacher used a variety of approaches that could have enhanced the students' metacognitive awareness. If an assumption is made that the control group teacher continued to support her students with metacognitive strategies during the intervention, then this could help to explain why the students had higher PSTs scores at post-test. One cannot be sure why MSM group did not show improvement in its MCAI mean scores. One suggestion could be that the group received effective factual teaching, but poor metacognitive strategies support from their regular teacher and hence high pre-test PSTs scores. The teachers also reported using different strategies to influence their students' motivational orientation. However, although there were differences in teachers' motivation strategies, these appeared to reflect different approaches to teaching rather than differences in their ability to motivate the

students. In addition, the students' self-reported motivational orientation across the three groups did not appear to differ as discussed in Chapter 6. As a result, it is possible that individual differences between students may be more important in determining their motivation, rather than the strategies used by the teacher. It also is the case that the control group students were preparing for their examinations and as a result most were likely to be motivated to learn about problem-solving in chemistry, but this was not apparent from the group interviews.

8.6 Overall conclusion drawn from the studies

This research was designed to find out whether interventions which teach metacognitive strategies could help students enhance their metacognitive skills and achievement during problem-solving in stoichiometry. Perhaps the most important finding from the research was that in both Study 1 and Study 2 the groups who had an intervention involving MSF significantly increased their chemistry problem-solving as assessed by the PST scores. These findings strongly suggest that MSF provides an effective way to support students in their ability to solve stoichiometry problems.

Ellis et al. (2014) suggest that teaching metacognitive strategies explicitly helps students to make achievement gains. MSF is designed to teach students metacognitive skills strategies explicitly during problem-solving and hence the significant gains in achievement reported in both Studies 1 and 2 (Delvecchio, 2011; Archer and Hughes, 2011). A complicating factor is that MSM group showed high pre-test PSTs mean scores and a low MCAI mean score. We cannot be sure why this was the case. A possible explanation could be that the teacher of MSM group might have been good at teaching the students factual knowledge or practicing chemistry problems, but had not supported the students to develop their metacognitive skills

awareness. This could also be the reason why there was no significant improvement of PSTs scores at post-test as it is possible that these students tended to rely on their knowledge rather than their metacognition (Haidar and Naqabi, 2008; Cardellini, 2002).

In the first study, the increase in PST scores was accompanied by a decrease in MCAI scores, and in the second study, there was also a decrease in the MCAI scores for the MSF and control groups who had significant improvements in their PST scores. Furthermore, no significant correlations were found between the MCAI and PST scores in both first and second study. However, findings from the group interviews suggested that there was a general link between MS awareness and PSTs achievement and this agrees with previous research (e.g. Zepeda et al., 2015; Zohar and Barzilai, 2013; Cook et al., 2013; Pennequin et al., 2010; Schraw et al; 2006; Rickey and Stacy, 2000; Thompson, 1990). Thus, findings presented in this thesis raise questions about the reliability and validity of the MCAI as a measure of metacognitive skills.

While the findings from Study 2 suggest that the MSF was a more effective instructional method in raising the students' achievement in stoichiometry, the control group also had an increase in the achievement (28.45%) which was much higher than that of the MSM group (3.2%) but lower than that of MSF group (46.35%). This anomaly could have been partly a result of the control group students' preparation for public exams during the time when the study was carried out and in addition, as reported in Chapter 7, the teacher of Group C taught the control group using metacognitive instructional approaches centred on fostering conceptual understanding. If teacher's teaching style was a factor in their achievement, then one would have expected to see high pre-test PSTs scores in the control group, and this group of students had mean scores midway between the other two groups.

The change in teachers for the MSM group before the study commenced makes it difficult to make an informed judgement about this group from what was reported by the teacher during the interview.

8.7 Implications for practice

This research offers a number of implications for educational practice. Firstly, teachers of chemistry would serve their students well if in the first instance; they improve on their metacognitive skills awareness. Baird (1998) observes that unless teachers themselves develop metacognitive strategies, they cannot help their students apply the same principles in the teaching of chemistry in general and stoichiometry in particular. They should focus on teaching conceptual development which gives students a conceptual understanding of the subject rather than just teaching students symbolic or algorithmic procedures which encourage rote learning. Secondly, students would significantly benefit from being taught metacognitive strategies during problem solving tasks in order to enhance their metacognitive skills awareness and use. Finally, with an improved MCAI, teachers could assess changes in their students' metacognitive skills awareness over time.

Improving teacher's awareness of metacognition

The outcomes of Study 4 reported in Chapter 7 suggest that some teachers could already be engaged in metacognitive instruction as seen in case of the teacher of the control group. Before providing training, policy makers could suggest carrying out a general assessment to ascertain the teachers' metacognitive awareness, so that training focuses on areas that require development. It was seen that teachers predominantly teach planning and monitoring skills in stoichiometry; therefore, it could mean that training would need to focus more on control and evaluation skills. The findings, although from a limited sample, suggest that teachers of science in

general and teachers of stoichiometry in particular, will need to be encouraged to use conceptual development within their subject domains. This is likely to help students to improve their metacognitive skills awareness and in answering relevant questions (Ellis et al., 2014; Haider and Naqabi, 2008; Robinson, 2003; Gabel, 1990). Furthermore, findings from Study 4 showed that those teachers who use metacognitive teaching approaches regularly help their students to achieve better results. This study confirmed the nexus between conceptual understanding and metacognitive awareness as shown by the findings from the control group. As argued in this thesis, students who have a conceptual understanding of metacognition achieve better results than students who have an algorithmic understanding (understanding of the procedure). This observation implies that teachers could benefit from training courses that focus on encouraging them to adopt teaching strategies that enable students to develop conceptual understanding. The teacher of the control group primarily focused on teaching students to develop conceptual understanding in her stoichiometry lessons and, as a result, her students developed metacognitive awareness and use.

Broadly, policy makers may consider introducing metacognitive training as part of chemistry teachers' education curriculum in teacher training institutions. When teachers have a developed metacognitive awareness, they are better equipped to engage their students in learning activities that help them to develop their metacognitive awareness and use (Wall and Hall, 2016). The current global attention being given to metacognitive instructional approaches at tertiary level could mean that instructors in the areas of engineering in general, could adopt aspects of the metacognitive skills framework and utilise metacognitive skills modelling to help students to develop their innovation and problem-solving skills.

Improving students' awareness of metacognition

Findings from Study 1 (Chapter 4) and Study 2 (Chapter 5) suggest that students can benefit from metacognitive instructional methods. The MSF intervention showed that students can experience a significant improvement in their achievement in stoichiometry problem-solving. However, these findings need to be replicated, given the outcome of Study 2. Teachers can better plan and structure their lessons in order to allow students to make use of the MSF as a tool that focuses problem-solving efforts in order to develop metacognitive skills. Generally, improvement in metacognition helps low-ability students boost their achievement scores (Pennequin et al., 2010; Swanson, 1990). Thus, MSF could be a valuable tool to guide lower performing students to improve on their problem-solving skills. This implies that MSF could be used as a tool for differentiated teaching approaches. The MSF offers an opportunity for teachers to develop their own awareness of metacognitive strategies because the framework carries written instructions which provide guidance on how to develop the four pillars of metacognitive strategies.

The MSF appears to be a more explicit instructional tool than the MSM and, when effectively taught, could help students make gains in their achievement not only in stoichiometry, but in other related subject domains such as mathematics and physics given that metacognitive skills are transferrable across other subject domains (e.g. Zohar and Barzilai, 2013; Sandi-Urena et al., 2011). The findings did not provide as much support for the use of MSM to increase metacognition and chemistry problem-solving. As a result, until further data is obtained about the effectiveness of MSM interventions, these should not be the first choice as a way to support metacognition and, when possible, evaluations of their effectiveness should be carried out on an informal or formal basis.

An improved MCAI designed to accurately assess secondary school students' metacognition could help provide essential information which gives an insight into students' metacognitive awareness and use. The mean score could be used to compare the metacognitive skilfulness of different groups of students (Sandi-Urena and Cooper, 2009) and teachers can use this information to better understand their students' thinking skills. This tool could provide teachers across different subject domains to identify students who have a poor awareness of metacognition and would stand to benefit from instructional interventions which help them increase their metacognitive awareness and use. The MCAI could also help teachers to identify those students with a tendency to rate themselves as highly metacognitive while their performance in learning tasks is poor. Generally, such students are more resistant to interventions compared to those who show an awareness of their skills limitations (Sandi-Urena and Cooper, 2009). The availability of this kind of information could assist teachers plan their instructional interventions in a more meaningful way that will see students improve their learning.

8.8 Limitations

The first major limitation of this study was the small sample size in Studies 1 and 2, thus care must be taken in generalising the findings from these two studies. The small sample size meant that the analyses had limited statistical power, hence the chances of finding group differences in the students' metacognitive skills awareness and use; and problem-solving abilities was reduced.

Another limitation was that Studies 1 and 2 did not control for ability levels between the control and intervention group nor was there random allocation of participants to conditions. This makes it difficult to be sure that the intervention was the sole

contributor to the observed changes in the students' metacognitive awareness and use. The groups were taught by different teachers and this could affect the students' general metacognitive awareness if the teachers' teaching approaches are different.

In both Studies 1 and 2, it was difficult to randomly allocate participants to groups as the participants were located in different campuses of the school. Furthermore, the control group was located in a different school, making it hard to control for other factors such school culture, student selection etc.

The intervention of one hour per week for three weeks may not have been long enough to allow students to develop their metacognitive skills. This change and transformation of problem-solving thinking processes, is something that may require longer periods of time (McLellan and Nicholl, 2011; Case and Gunstone, 2002); and other interventions focussing on developing students' metacognition took place over long periods of time and involved large samples (Sandi-Urena et al., 2012).

Another issue is that while the MCAI was designed to assess metacognitive awareness in chemistry, it was originally designed and validated to assess metacognitive awareness among tertiary level students and this could possibly make it unsuitable for use among secondary school students. However, there was no evidence to suggest that participants found the inventory statements inaccessible although there were eight negatively worded statements.

Measuring the students' utilization of metacognitive skills is a big challenge and previous research has identified lack of evidence on construct validity as a major problem in assessing metacognition (Pintrich et al., 2000). In addition, there is a discrepancy between theoretical predictions about metacognition and the data produced by the MCAI. Metacognitive skills usually are broken down into planning,

monitoring, control and evaluation, yet 'factor analysis of self-reports such as the MCAI generates only one factor (Cooper and Sandi-Urena, 2009). This suggests that this self-report questionnaire could fail to capture students' real use of metacognitive skills (Delvecchio, 2011). There is also the view that metacognitive processes are real-time or 'in-the-moment' processes, and students may not necessarily recall their metacognitive experiences at the time of completing the inventory questionnaire (Gardner, 1987). The MCAI involves a Likert scale for the questions, measuring how frequently students used their MS and this could have failed to capture the levels of sophistication to which the students used their MS. Given that Likert scales are ordinal and uni-dimensional, the distance between points of choice is not equal therefore they fail to capture the exact attitudes of the respondents.

Another challenge with MCAI is the bidirectional interpretation of scores. A high MCAI score is usually assumed to reflect higher levels of metacognitive awareness in a single assessment scenario. However, the decline in MCAI scores between pre-test and post-test is considered to indicate an improvement in MCAI awareness and it has been argued that MCAI is a 'habitual behaviour self-report and not an attitude inventory' (Sandi-Urena et al., 2011, p.333). This argument is supported by the view that MCAI assesses the participant's habitual use of the construct and not necessarily the participant's perception of the importance of it (Sandi-Urena et al., 2011). It is further argued that as the participants increase their metacognitive awareness, so does their perception of the importance they attach to the construct and consequently they become stringent in their self-rating resulting in the decline of MCAI scores at post-test self-assessment.

A further limitation is that there was a change of teachers for MSM group during the study and the teacher who was interviewed for Study 4 had not taught the topic of

stoichiometry. Therefore the responses given by the teacher of MSM group did not necessarily give an accurate reflection of the impact of his teaching styles on the students' metacognitive awareness and use in stoichiometry. The students in Group C were preparing for public exams during the course of Study 2; therefore, their level of commitment to the learning activities might have been higher than that of the experimental groups, resulting in their achievement scores surpassing those of MSM group.

8.9 Further research

The findings from in this thesis have raised more questions than answers and therefore there is large scope for further research. The difficulty of assessing students' metacognition remains a challenge for researchers in this field. This is partly due to the absence of clarity on the definition of metacognition (Dinsmore et al., 2008; Pintrich et al., 2000). Assessing metacognition is further complicated by the existence of a disconnection between what the theory predicts and what is generated by data.

An immediate area of further research would consider this question; what is the best way to assess students' MS use while solving problems in chemistry and stoichiometry in particular? Some researchers have suggested the use of a multi-method approach to assessing MS and one of the methods suggested is the use of a computer based platform such as Interactive Multimedia Exercises IMMEX (Cooper, Sandi-Urena and Stevens, 2012). IMMEX is designed to monitor students' use of strategies as they solve problems and it generates a large amount of data. This is yet to be used in studies at secondary school level.

The contribution of instructional methods to developing students' MS awareness and use during problem-solving remains uncertain. The findings that the MSF resulted in significant improvement in PST scores in Studies 1 and 2 is encouraging, less

encouraging is the finding that in Study 2 the control group out performed experimental MSM group. Further research is required to establish the differential contribution of instructional methods to the development of students' MS awareness and use. Further comparisons of MSF and MSM are likely to be helpful in achieving this.

Another area that requires further inquiry is the correlation between MS and achievement, but this will require a better assessment tool than the MCAI, in order to capture the students' awareness and use of MS. The contribution of each MS component to the overall MS awareness and use requires further research using the appropriate assessment tools. Further studies would need to control for ability levels across the groups and ideally all groups should be from the same school and should involve large samples. The study will need to be carried out over extended periods of time (something difficult to do in schools) to allow for the development of MS awareness and use.

8.10 Conclusions

This thesis was designed to explore the link between metacognitive instructional methods and students' development of MS awareness and use during problem-solving in stoichiometry and the link between problem-solving skills and MS awareness and use over time. The study was also designed to explore insights provided by interviews with teachers and students about the teaching and learning of metacognitive skills respectively.

This study has made contributions to our understanding of metacognition and learning. Firstly, using a quasi-experimental research design contributed to a need for 'controlled research designs' identified in a major review of the topic by Zohar and

Barzilai (2013, p.2). Secondly, findings from Studies 1 and 2 suggest that problem-solving skills in stoichiometry can be improved by using metacognitive training involving the MSF. The findings also provide support for the idea that these improvements in stoichiometry occurred as a result in improvements in metacognitive skills as the interventions were focussed on metacognitive skills. However, it needs to be acknowledged that consistent evidence of significant changes in MCAI scores in both experiments was not obtained; such a change might have been expected on the basis of previous research (e.g. Cook et al., 2013; Sandi-Urena and Cooper, 2009; Haidar and Naqabi, 2008).

Finally, the study has highlighted that self-report questionnaire measures are limited in capturing metacognitive processes in secondary school students. The findings in Chapters 6 and 7 also showed the potential of semi-structured interviews to gain insights into metacognition and the teaching of metacognition, and suggest such interviews could provide a valuable addition to the research techniques used in this field of study.

References

- Ambrose, S., M. Bridges, M. DiPietro, M. Lovett, & M. Norman. (2010). *How Learning Works*. San Francisco: Jossey-Bass.
- Ames, C, & Archer, J. (1988). Achievement goals in the classroom: Student learning strategies and motivation processes. *Journal of Educational Psychology*, 80, pp. 260-267.
- Alvarez, A., & Adelman, H.S. (1986). Overstatements of self-evaluations by students with psycho- educational problems. *Journal of Learning Disabilities*, 19, 567-571.
- Archer, A.L. & Hughes, C.A. (2011). *Explicit Instruction: Effective and Efficient Teaching*. New York: The Guilford Press.
- Astington, J. W., Harris, P. L., & Olson, D. (eds.), (1988). *Developing Theories of Mind*, Cambridge University Press: Cambridge.
- Bahrack, H.P. (1984). Semantic memory content in permastore: fifty years of memory for Spanish learned in school. *Journal of Experimental Psychology: General*, 113(1), pp. 1-37.
- Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.
- Baird, J. (1998). A view of quality in teaching. In *International handbook of science education*, ed. B. J. Fraser and K. G. Tobin, 153–67. Dordrecht, Netherlands: Kluwer Academic Publishers.
- Berg, B. L. (2007). *Qualitative research methods for the social sciences*. London: Pearson
- Blank, L. M., & Hewson, P. W. (2000). A metacognitive learning cycle: A better warranty for student understanding? *Science Education*, 84(4), pp. 486–506.
- Boekaerts, M. (1999). Self-regulated learning: where we are today. *International Journal of Educational Research*, 31, pp. 445-457.
- BouJaoude, S., and H. Barakat. (2003). Students' problem solving strategies in stoichiometry and their relationships to conceptual understanding and learning approaches. *Electronic Journal of Science Education*, 7(3), <http://wolfweb.unr.edu/homepage/crowther/ejse/boujaoude.pdf> (accessed 5 October, 2016).
- Boyce, C., & Neale, P. (2006). Conducting in-depth Interviews: A Guide for Designing and Conducting In-Depth Interviews. *Pathfinder International Tool Series*, 2, pp. 1-16.
- Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology, *Qualitative Research in Psychology*, 3(2), pp. 77-101.
- British Education Research Association/BERA (2011).

Available at <https://www.bera.ac.uk/> (Accessed Summer, 2016)

Brown, A. L. (1987). Metacognition, executive control, self-regulation and other more mysterious mechanisms. In F. Weinert & R. Kluwe (Eds.), *Classroom management* pp. 144–181. Hillsdale, NJ: Erlbaum.

Brown, A.L. (1978). Knowing when, where and how to remember: A problem of metacognition. In R. Glaser (Ed.), *Advances in instructional psychology* pp. 77-265. New York: Halsted Press.

Brown, A. L., & DeLoache, J. S. (1978). Skills, plans, and self-regulation. In R. S. Siegel (Ed.), *Children's thinking: What develops?* pp. 3–35. Hillsdale, N.J: Erlbaum.

Burrows ,D., & Kendall S. (1997). Focus group interviews: What are they and how can they be used in nursing and health care research? *Social Sciences in Health*, 3, pp. 244–253.

Butler, D.L. (1998a). Metacognition and learning disabilities. In Wong, B.Y.L. (Ed.) *Learning about learning disabilities*, Second edition, pp. 277-307. New York: Academic Press.

Butler, D.L., & Winne, P.H. (1995). Feedback and self-regulated learning: A theoretical synthesis. *Review of Educational Research*, 65(3), pp. 245-281.

Burguess, H., Sieminski, S. And Arthur, L.(2007). *Achieving Your Doctorate in Education*. London: Sage.

Callender, A. A., Franco-Watkins, A.M., and Roberts, A. S. (2016).Improving metacognition in the classroom through instruction, training, and feedback. *Metacognition Learning*, 11, pp. 215–235.

Cardellini, L. (2002). An interview with J. Dudley Herron. *Journal of Chemical Education* 79(1), pp. 3–9.

Case, J., & Gunstone, R. (2002).*Creating active learning environments*. San Francisco: Jossey-Bass.

Ciardiello, A. V. (1998). "Did You Ask a Good Question Today? Alternative Cognitive and Metacognitive Strategies." *Journal of Adolescent and Adult Literacy*, 42, pp. 210-19.

Cohen, L. Manion, L. and Morrison, K. (2007). *Research methods in education* 6th Edition. London: Routledge.

Cohors-Fresenborg, E., Kramer, S., Pundsack, F., Sjuts, J., and Sommer, N. (2010). The role of metacognitive monitoring in explaining differences in mathematics achievement. *ZDM Mathematics Education*, 42, pp. 231-244.

Cook E., Kennedy, E., and McGuire, S.Y. (2013) Effect of Teaching Metacognitive Learning Strategies on Performance in General Chemistry Courses. *Journal of Chemical Education*, 90, pp. 961-967.

- Cooper M. M., & S. Sandi-Urena S. (2009). Design and Validation of an Inventory to Assess Metacognitive Skilfulness in Chemistry Problem-solving. *Journal of Chemical Education*, 86(2), pp. 240-245.
- Cracolice, M. S., Deming, J.C. & Ehlert, B. (2008). "Concept Learning versus Problem-solving: a cognitive difference." *Journal of Chemical Education*, 85(6), pp. 873- 878.
- Cresswell, J.W.(Ed).(2008). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches* (3rd ed.). Los Angeles: Sage.
- Cromley, J. G., & Azevedo, R. (2006). Self-report of reading comprehension strategies: What are we measuring? *Metacognition and Learning*, 1, pp. 229–247.
- Crotty, M. (2003). *The Foundations of Social Research: Meaning and Perspectives in the Research Process*, London: Sage Publications.
- Davis, E. A. (2003). Prompting middle school science students for productive reflection: Generic and directed prompts. *The Journal of the Learning Sciences*, 12(1), pp. 91–142.
- De Bruin A.B. H., Kok, E. M., Lobbestael, J. & de Grip, A. (2017). The impact of an online tool for monitoring and regulating learning at university: overconfidence, learning strategy, and personality. *Metacognition Learning*, 12, pp. 21–43.
- Delvecchio, F. (2011). Students' use of Metacognitive Skills while problem solving in High school Chemistry.
Available from: <http://qspace.library.queensu.ca/handle/1974/6703> Accessed on: 16 August 2012.
- Dinsmore, D. L., Alexander, P. A., & Loughlin, S. M. (2008). Focusing the conceptual lens on metacognition, self-regulation, and self-regulated learning. *Educational Psychology Review*, 20, pp. 391–409.
- Dinsmore, D.L. (2017). Examining the ontological and epistemic assumptions of research on metacognition, self-regulation and self-regulated learning, *Educational Psychology*, 37(9), pp. 1125-1153.
- Efklides, A. (2011). Interactions of Metacognition with Motivation and Affect in Self-Regulated Learning: The MASRL Model. *Educational Psychologist* 46(1), pp. 6–25.
- Efklides, A. (2008). Met cognition: Defining Its Facets and Levels of Functioning In Relation to Self-Regulation and Co-regulation A. *European Psychologist* 13(4), pp. 277–287.
- Efklides, A. (2005). Metacognition and affect: What can metacognitive experiences tell us about the learning process? *Educational Research Review*, 1, pp. 3-14.
- Efklides, A., & Vauras, M. (Guest eds.) (1999). Metacognitive experiences and their role in cognition (Special issue). *European Journal of Psychology of Education*, 14 (4) pp. 455-459.

Efklides, A., Niemivirta, M., & Yamauchi, H. (2003). Motivation and self-regulation: Processes involved and context effects—A discussion. *Psychologia: An International Journal of Psychology in the Orient*, 46, pp. 38–52.

Ellis, A.K., Denton, D. W., Bond, J. B (2014). An analysis of research on metacognitive teaching strategies. *Procedia - Social and Behavioural Sciences*, 116, pp. 4015 – 4024.

Fernandez, J & Jamet, E.(2017).Extending the testing effect to self-regulated learning. *Metacognition and Learning*, 12, pp. 131-156.

Flavell, J.H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, 34(10), pp. 906-911.

Flavell, J. H. (1992). Perspectives on perspective taking. In Beilin, H., and Pufall, P. (eds.), *Piaget's Theory: Prospects and Possibilities*, pp. 109–139. Hillsdale, NJ: Erlbaum.

Francisco, J. S., & Nicoll, G. (1998). Integrating multiple teaching methods into a general chemistry classroom. *Journal of Chemical Education*, 75(2), pp. 210–213.

Gabel, D. (1999). Improving teaching and learning through chemistry education research: A look to the future. *Journal of Chemical Education*, 76(4), pp. 548–54.

Gardner, H. (1987). *The mind's new science A history of the cognitive revolution*. New York: Basic.

Georghiades, P. (2004a). From the general to the situated: Three decades of metacognition. *International Journal of Science Education*, 26(3), pp. 365-383.

Grix, J. (2002). Introducing Students to the Generic Terminology of Social Research. *Politics*, 22(3), pp. 175-176.

Gunstone, R. (1999). The importance of specific science content in the enhancement of metacognition. In P. J. Fensham, R. F. Gunstone, & R. T. White (Eds.), *The content of science: A constructivist approach to its teaching and learning*, pp. 131–146. London: The Falmer Press.

Haidar, A.H., & Naqabi, A.K. (2008). Emiratii high school students' understandings of stoichiometry and the influence of metacognition on their understanding. *Research in Science & Technological Education*, 26(2), pp. 215–237.

Hammersley, M. (2012). Methodological Paradigms in Educational Research, British Educational Research Association on-line resource. Available on-line at <https://martynhammersley.files.wordpress.com/2013/11/methodological-paradigms-4.pdf> on 03/01/2018

Hill, K., & Wigfield, A. (1984). Test anxiety: A major educational problem and what can be done about it. *Elementary School Journal*, 85, pp. 105-126.

Howard, B. C., McGee, S., Shia, R & Hong, N. S. (2001). Computer-Based Science Inquiry: How Components of Metacognitive Self-Regulation Affect Problem-Solving.

Presented at the Annual Meeting of the American Educational Research Association (AERA), Seattle, WA.

Huffman, D. (1997). Effect of explicit problem-solving instruction on high school students' problem-solving performance and conceptual understanding of physics. *Journal of Research in Science Teaching*, 34(6), pp. 551–570.

Husén, T. (1997). Research paradigms in education. In J. P. Keeves (Ed.), *Educational research, methodology, and measurement: An international handbook*, pp. 16-21. Oxford, UK: Pergamon.

Jacobse A. E., & Harskamp E.G. (2012). Towards efficient measurement of metacognition in mathematical problem solving. *Metacognition Learning*, 7, pp. 133–149.

Johnson, B., & Onwuegbuzie, A. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, 33(7), pp. 14-26.

Kipnis, M. & Hofstein, A. (2008). The Inquiry Laboratory as a Source for Development of Metacognitive Skills. *International Journal of Science and Mathematics Education*, 6, (3) pp. 601-627.

Kistner, S., Rakoczy, K., & Otto, B. (2010). Promotion of self-regulated learning in classrooms: Investigating frequency, quality, and consequences for student performance. *Metacognition and Learning*, 5 (2), pp. 157-171.

Kitzinger, J. (1994). The methodology of focus group: the importance of interactions between research participants. *Sociology of Health and Illness*, 16, pp. 103–121.

Kluwe, R. H. (1987). Executive decisions and regulation of problem solving behaviour. In F. E. Weinert, & R. H. Kluwe (Eds.), *Metacognition, motivation, and understanding*, pp.31–64. Hillsdale, N.J: Erlbaum.

Krueger, RA. (1994). *Focus Groups: A Practical Guide for Applied Research*. Thousand Oaks, CA: Sage Publications.

Krueger, R.A. & Casey, M.A. (2000). *Focus Groups: A Practical Guide for Applied Research*, 3rd Edition. Thousand Oaks, CA: Sage Publications.

Kvale, S. (2003). The psychoanalytic interview as inspiration for qualitative research. In P. M. Camic, J. E. Rhodes, & L. Yardley (Eds.), *Qualitative research in psychology*, pp. 275– 297. Washington, USA: American Psychological Association.

Kuhn, D. (1991). *The skills of argument*. Cambridge: Cambridge University Press.

Kuhn, D. (2000). 'Metacognitive development'. *Current Directions in Psychological Science*, 9(5), pp. 178-181.

Leutwyler, B. 2009. "Metacognitive Learning Strategies: Differential Development Patterns in High School." *Metacognition and Learning*, 4(2), pp. 111–123.

Lompscher, J. (1994). Learning strategies: An essential component of learning activity. *Lern-und Lehrforschung*, 7, pp. 78–95.

Mayer, R. E. (2005). The failure of educational research to impact educational practice: Six obstacles to educational reform. In G. D. Phye, D. H. Robinson, & J. Levin (Eds.), *Empirical methods for evaluating educational interventions*, pp. 67–81. San Diego: Elsevier Academic Press.

McLellan, R., & Nicholl, B. (2011). 'If I was going to design a chair, the last thing I would look at is a chair': product analysis and the causes of fixation in students' design work 11–16 years. *International Journal of Technology and Design Education*, 21(1), pp. 71–92.

McCutcheon, G. (1992). Facilitating teacher personal theorizing. In Ross, E. W., Cornett, J. W., and McCutcheon, G. (eds.), *Teacher Personal Theorizing: Connecting Curriculum Practice, Theory, and Research*. Albany, NY: State University of New York Press.

McElwee, S. (2009). Special Education Support Service, Version 1. Available from: http://www.sess.ie/sites/default/files/Projects/Equality_of_Challenge/SESS_Metacognition_Resource_V1.pdf: Accessed on 24 January 2018.

Meltzer, L., Roditi, B., Houser, Jr., R.F., & Perlman, M. (1998). Perceptions of academic strategies and competence in students with learning disabilities. *Journal of Learning Disabilities*, 31, pp. 437–451.

Montgomery, D. E. (1992). Young children's theory of knowing: The development of a folk epistemology. *Developmental Review*, 12, pp. 410–430.

Morgan, D. (1996). *Qualitative Research Methods Series 2nd Edition*. Thousand Oaks, London: Sage Publications.

Morgan, D. (2013). Pragmatism as a Paradigm for Social Research. *Qualitative Inquiry*, 20(8), pp. 1045–1053.

Nolen, S. (1988). Reasons for studying: Motivational orientations and study strategies. *Cognition and Instruction*, 5, pp. 269–287.

Osborne, J.W. (1998). Measuring metacognition: Validation and assessment of cognition monitoring effectiveness. Unpublished PhD thesis. Buffalo: State University of New York.

Pennequin, V., Sorel, O., Nanty, I. & Fontaine, R. (2010). Metacognition and low achievement in mathematics: The effect of training in the use of metacognitive skills to solve mathematical word problems. *Thinking and Reasoning*, 16(3), pp. 198–220.

Pajares, F. (1996). Self-efficacy beliefs in academic settings. *Review of Educational Research*, 66(4), pp. 543–578.

- Paris, S. G., & Oka, E. (1986). Children's reading strategies, metacognition and motivation. *Developmental Review*, 6, pp. 25-86.
- Paris, S. G.; & Paris, A. H. (2001). Classroom Applications of Research on Self-Regulated Learning *Educational Psychology*, 36, pp. 89–101.
- Pine, K., & Messer, D. (1999). The teachability of children with naive theories. *British Journal of Educational Psychology*, 69, pp. 201-211.
- Pintrich, P. R., & De Groot, V.E. (1990). Motivational and Self-Regulated Learning Components of Classroom Academic Performance. *Journal of Educational Psychology*, 82(1), pp. 33-40.
- Pintrich, P. R. (1988). A process-oriented view of student motivation and cognition. In J. S. Stark & L. Mets (Eds.), *Improving teaching and learning through research. New directions for institutional research*, 57, pp. 55-70. San Francisco: Jossey-Bass.
- Pintrich, P. R., Cross, D. R., Kozma, R. B., & McKeachie, W. J. (1986). Instructional psychology. *Annual Review of Psychology*, 37, pp. 611-651.
- Pintrich, P.R., Anderman, E.M., & Klobucar, C. (1994). Intra-individual differences in motivation and cognition in students with and without learning disabilities. *Journal of Learning Disabilities*, 27, pp. 360-370.
- Pintrich, P. R. (1999). The role of motivation in promoting and sustaining self-regulated learning. *International Journal of Educational Research*, 31(6), pp. 459–470.
- Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation*, pp. 451–502. San Diego, CA: Academic
- Rabiee F (1999). Focus-group interview and data analysis. *Proceedings of the Nutrition Society*, 63, pp. 655–660.
- Research Council of Zimbabwe. Available at <http://www.rcz.ac.zw/> (Accessed Summer, 2016)
- Richardson, C.A., & Rabiee, F. (2001). 'A Question of Access' – an exploration of the factors influencing the health of young males aged 15–19 living in Corby and their use of health care services. *Health Education Journal*, 60, pp. 3–6.
- Rickey, D., & Stacy, A. M. (2000). The role of metacognition in learning chemistry. *Journal of Chemical Education*, 77(7), pp. 915.
- Robinson, W.R. (2003). Chemistry problem-solving: Symbol, macro, micro, and process aspects. *Journal of Chemical Education*, 80(9), pp. 978–982.
- Robson, M. (2002). *Problem-solving in Groups*. Aldershot: Gower Publishing, Ltd.
- Rozencwajg, P. (2003). Metacognitive factors in scientific problem-solving strategies. *European Journal of Psychology of Education*, 18(3), pp. 281-294.

Sandi-Urena, S. and Copper, M.(2009).Design and Validation of an Instrument To Assess Metacognitive Skilfulness in Chemistry Problem Solving. *Journal of Chemical Education*, 86(2), pp. 240-245.

Sandi-Urena, S., Cooper, M.M., and Stevens, R.H. (2011) Enhancement of Metacognitive Use and Awareness by means of Collaborative Intervention. *International Journal of Science Education*, 33(3), pp. 323-340.

Sandi-Urena, S., Cooper, M. & Stevens, R. (2012). Effect of Cooperative Problem-Based Lab Instruction on Metacognition and Problem-Solving Skills. *Journal of Chemical Education*, 89, pp. 700–706.

Scharlach, T.D. (2008). Improving comprehension and metacognition through active engagement with the text. Presented at the National Reading Conference 58th Annual Meeting, Orlando, FL.

Searle, J. R. (2009). Language and Social Ontology. In C. Mantzavinos (Ed.). *Philosophy of the Social Sciences. Philosophical Theory and Scientific Practice*. Cambridge: Cambridge University Press

Shavelson, R. J., & Towne, L. (Eds.). (2002). *Scientific research in education*. Washington, DC: National Academy Press.

Schraw, G. (1998). Promoting general metacognitive awareness. *Instructional Science*, 26, pp. 113– 125.

Schraw, G. (2001). Promoting general metacognitive awareness. In H. J. Hartman (Ed.), *Metacognition in learning and instruction*, pp. 3–16. Dordrecht: Kluwer.

Schraw, G., Brooks, D. W., & Crippen, K. J. (2005). Using an interactive, compensatory model of learning to improve chemistry teaching. *Journal of Chemical Education*, 82(4), pp. 637–640.

Schraw G., Crippen K.J., and Hartley K. (2006). ‘Promoting Self-regulation in Science Education: Metacognition as Part of a Broader Perspective on Learning.’ *Research in Science Education*, 36(1-2), pp. 111-139.

Schraw, G. and Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology*, 19, 4pp. 60-475.

Schraw, G., Dunkle, M. E., Bendixen, L. D., & Roedel, T. D. (1995). Does a general monitoring skill exist? *Journal of Educational Psychology*, 87, pp. 433–444.

Schraw, G. & Moshman, D. (1995). Metacognitive theories. *Educational Psychology Review*, 7(4), pp. 351-371.

Schmitt, N., & Stuits, D. (1985). Factors defined by negatively keyed items: The result of careless respondents? *Applied Psychological Measurement*, 9, pp. 367-373.

- Schunk, D. (1985). Self-efficacy and school learning. *Psychology in the Schools*, 22, pp. 208-223.
- Schunk, D. (1996). Goal and self-evaluative influences during children's cognitive skill learning. *American Educational Research Journal*, 33(2), pp. 359–382.
- Schunk, D. H., & Zimmerman, B. J. (1998). *Self-Regulated Learning: From Teaching to Self-Reflective Practice*. New York: Guilford Press.
- Scruggs, E.; Mastropieri, M. A.; Monson, J.; & Jorgenson, C. (1985, Fall). "Maximizing what gifted students can learn: Recent findings of learning strategy research." *Gifted Child Quarterly*, 29(4), pp. 181-185.
- Snow, R. (1989). Aptitude-treatment interaction as a framework for research on individual differences in learning. In P. Ackerman, R. Sternberg, & R. Glaser (Eds.), *Learning and individual differences*, pp. 13-59. New York: Freeman.
- Swanson, H. L. (1990). Influence of metacognitive knowledge and aptitude on problem solving. *Journal of Educational Psychology*, 82(2), pp. 306.
- The Research council of Zimbabwe (2014).
Available from: <http://www.rcz.ac.zw/>. Accessed on 15 December 2017
- Tashakkori, A., & Teddlie, C. (2010). Overview of contemporary issues in mixed methods research. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods research for the social & behavioural sciences* (2nd ed., pp. 1-44). Thousand Oaks, CA: SAGE.
- Tavol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education* 2, pp. 53-55.
- Taylor S (1999). Better learning through better thinking: Developing students' metacognitive abilities", *Journal of College Reading and Learning*, 30(1), pp.34.
- Taylor, C.P., and Medina, D.N.M. (2013). Educational research paradigms: From positivism to multiparadigmatic. *Journal of Meaning-Centred Education*, 1, pp. 1-17.
- Thomas, G., Anderson, D., & Nashon, S. (2008). Development of an instrument designed to investigate elements of science students' metacognition, self-efficacy and learning processes: The SEMLI-S. *International Journal of Science Education*, 30(13), pp. 1701–1724.
- Tsai, C. (2001). A review and discussion of epistemological commitments, metacognition, and critical thinking with suggestion on their enhancement in internet-assisted chemistry classrooms. *Journal of Chemical Education*, 78(7), pp. 970–974.
- Veenman, M. V. J. (2012). Metacognition in science education: Definitions, constituents, and their intricate relation with cognition. In A. Zohar & Y. J. Dori (Eds.), *Metacognition in science education: Trends in current research*, pp. 21–36. Dordrecht: Springer.

Veenman, M. V. J. (2011). Learning to self-monitor and self-regulate. In R. E. Mayer & P. A. Alexander (Eds.), *Handbook of research on learning and instruction*, pp. 197–218.

Veenman, M. V. J., & Spaans, M. A. (2005). Relation between intellectual and metacognitive skills: Age and task differences. *Learning and Individual Differences*, 15(2), pp.159–176.

Veenman, M., & Elshout, J. J. (1999). Changes in the relation between cognitive and metacognitive skills during the acquisition of expertise. *European Journal of Psychology of Education*, 14, pp. 509–523.

Veenman, M. V. J., Elshout, J. J., & Meijer, J. (1997). The generality vs. domain-specificity of metacognitive skills in novice learning across domains. *Learning and Instruction*, 7, pp. 187–209.

Vosniadou, S. (1994). Capturing and modelling the process of conceptual change. *Learning and Instruction*, 4(1), pp. 45–69.

Wall, K. And Hall, E. (2016). Teachers as metacognitive role models. *European Journal of Teacher Education*, 39(4), pp. 403-418.

Webb, N. W., & Palincsar, A. S. (1996). Group processes in the classroom. In D. C. Berliner & R. C. Calfee (Eds.), *The handbook of educational psychology*, pp. 841–873. New York: Macmillan.

Weir, C. (1998). "Using Embedded Questions to Jump-start Metacognition in Middle School Remedial Readers." *Journal of Adolescent & Adult Literacy*, 4, pp. 458-67.

Weinert, F. (1987). Metacognition and motivation as determinants of effective learning and understanding. In F. Weinert & R. Kluwe (Eds.), *Metacognition, motivation, and understanding*, pp.1-15. Hillsdale, NJ: Erlbaum.

Weinert & R. H. Kluwe (Eds.) (1987). *Metacognition, motivation and understanding*, pp. 31–64. Hillsdale, N.J: Erlbaum.

West SG, Finch JF, Curran PJ.(1995). Structural equation models with no-normal variables: problems and remedies. In: Hoyle RH, editor. *Structural equation modelling: Concepts, issues and applications*, pp. 56–75. Newbery Park, CA: Sage.

Wildemuth, B.M. (1993). Post-positivist research: Two examples of methodological pluralism. *Library Quarterly*, 63(4), pp. 450-468.

Willis, J.W. (2007). *Foundations of qualitative: interpretive and critical approaches*. London: Sage.

Wigfield, A., & Eccles, J. (1989). Test anxiety in elementary and secondary school students. *Educational Psychologist*, 24, pp. 159-183.

Winne P. H., Hadwin A. F. (1998). "Studying as self-regulated engagement in learning," In *Metacognition in Educational Theory and Practice*, pp.277–304.eds Hacker D., Dunlosky J., Graesser A., editors. Hillsdale, NJ: Erlbaum.

Winne, P. H. (1996). A metacognitive view of individual differences in self-regulated learning. *Learning and Individual Differences*, 8, pp. 327–353.

Winne, P. H. (1995). Inherent details on self-regulated learning. *Educational Psychologist*, 30(4), pp. 173–187.

Winne, P. H. (2010). Improving measurements of self-regulated learning. *Educational Psychologist*, 45(4), pp. 267–276.

Winne, P. H., Jamieson-Noel, D. L., & Muis, K. (2002). Methodological issues and advances in researching tactics, strategies, and self-regulated learning. In P. R. Pintrich and M. L. Maehr (Eds.), *Advances in motivation and achievement: New directions in measures and methods*, 12, pp. 121-155. Greenwich, CT: JAI Press.

Whitebread D., Coltman P., Pasternak D.P., Sangster C., Grau V., Bingham S., Almeqdad Q., and Demetriou D. (2009) 'The development of two observational tools for assessing metacognition and self-regulated learning in young children'. *Metacognition and learning*, 4(1), pp. 63-68.

Young, A., & D. J. Fry (2008). Metacognitive awareness and academic achievement in college students. *Journal of the Scholarship of Teaching and Learning*, 8(2), pp. 1-10.

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy-empowering research and informing instruction. *International Journal of Science Education*, 28(2–3), pp. 291–314.

Zepeda, C.D., Richey, J.E., Ronevich, P., & Nokes-Malach, T.J. (2015). Direct Instruction of Metacognition Benefits Adolescent Science Learning, Transfer, and Motivation: An In Vivo Study. *Journal of Educational Psychology*, 107(4), pp. 954-970.

Zimmerman, B.J. (1989). A Social Cognitive View of Self-Regulated Academic Learning. *Journal of Educational Psychology* 1989, 81(3), pp. 329-339.

Zimmerman, B. J. (1995). Self-regulation involves more than metacognition: A social cognitive perspective. *Educational Psychologist*, 30, pp. 217–221.

Zimmerman, B. (2000). 'Attaining self-regulated learning: A social-cognitive perspective. In Boekaerts, M., Pintrich, P. & Zeidner, M. (Eds.), *Handbook of self-regulation*, pp.13-39. San Diego, CA: Elsevier Academic Press.

Zimmerman, B., & Pons, M. (1986). Development of a structured interview for assessing student use of self-regulated learning strategies. *American Educational Research Journal*, 23, pp. 614-628.

Zohar, A. and Barzilai, S. (2013). A review of research on metacognition in science education: current and future directions. *Journal of Studies in Science and Education*, 49(2), pp. 1-50.

Appendix 1

METACOGNITIVE SKILLS FRAMEWORK

The actual problem
set here

Current knowledge	Planning	Monitoring	Control	Evaluation
What have learnt that may be relevant to solving this problem?	<p>Read the problem</p> <p>Determine the goal</p> <p>Sort the information into relevant and irrelevant</p> <p>Break down the problem into small chunks</p> <p>Establish the relationship among any given data</p> <p>Decide on a strategy or method to find a solution</p>	<p>Check that you are using the correct strategy</p> <p>Revise every step you have taken</p> <p>Rate your effort on task</p> <p>Consult each other if not sure</p> <p>Check for errors in the procedure</p> <p>Correct any errors and proceed</p>	<p>Change your strategy or method after monitoring</p> <p>Consult and select a new strategy</p> <p>Check your strategy for effectiveness e.g. compare with others</p> <p>Ask for help from peers/teacher if strategy doesn't work</p> <p>Review notes</p>	<p>Review your solution and explain its correctness</p> <p>Explain how you arrived at your solution</p> <p>Compare solution with that of others</p> <p>Rate effort expenditure; was the problem difficult or easy?</p> <p>Could you have solved the problem differently?</p>

Appendix 2

METACOGNITIVE SKILLS MODELLING (MSM)

The main difference between MSF and teacher modelling is that in the MSF the students are given the framework with all MS components explicitly described. The students follow the MS component descriptors as they solve the problem step by step. In teacher modelling the teacher uses a typical example to show how the problem is solved by describing the steps applying MS.

Planning phase

1. I read the question to make sure that I understand what the question requires me to do (identifying task demand)
2. I breakdown (if it's long) the problem into chunks and isolate irrelevant information and choose the data to use.
3. I select a strategy to solve the problem using the selected data.

Monitoring phase

1. I check to see that I am using the correct strategy/method
2. I revise every step to make sure that calculations are accurate
3. If I am not sure consult my notes, my peers or the teacher
4. I check for errors before proceeding to the next stage of solving the problem

Control

1. If I realise that the method I am using is not working, I choose another method and start again.
2. I check to see if the new method is giving me expected results by comparing my solution with that of my peers.
3. If the new method fails to give me the expected solution then I can ask my peers or the teacher for help. I could revise my notes to improve on my knowledge of the topic before trying to solve the problem again.

Evaluation

1. I review my solution to check for correctness. I may need to quickly check through all stages that I followed in my calculations once more to see if there are no errors.
2. I should make sure that I am able to explain each step that I followed to arrive at my answer.
3. I will check to see if I used a different strategy from that used by others.
4. I will consider the amount of effort I put into solving the problem and rate the problem in terms of difficulty. Was it easy or difficult?

Appendix 3

METACOGNITIVE ACTIVITIES INVENTORY (MCAI)

Code Name: _____

Please read the following sentences. *Circle* a value from 1 (never) to 5 (Always) for each statement to describe the way you are when you are trying to solve a problem. Think back to the problem you just attempted. What do you do before you begin a solution? What do you do while you are working on the problem? What do you do after you have finish working on the problem? There are no right answers. Please describe yourself as you are not how you think you should be. This will not be graded.

Survey Scale: 1 = Never ...5 = Always

1. I read the statement of a problem carefully to fully understand it and determine what the question requires me to do.	1 2 3 4 5
2. When I do assigned problems, I try to learn more about the concepts so that I can apply this knowledge to test problems	1 2 3 4 5
3. I sort the information in the statement and determine what is relevant.	1 2 3 4 5
4. Once a result is obtained, I check to see that it agrees with what I expected.	1 2 3 4 5
5. I try to relate unfamiliar problems with previous situations or problems solved.	1 2 3 4 5
6. I try to determine the form in which the answer or product will be expressed.	1 2 3 4 5
7. If a problem involves several calculations, I make those calculations separately and check the intermediate results.	1 2 3 4 5
8. I clearly identify the goal of a problem (the unknown variable to solve for or the concept to be defined) before attempting a solution.	1 2 3 4 5
9. I consider what information needed might not be given in the statement of the problem.	1 2 3 4 5
10. I try to double-check everything: my understanding of the problem, calculations, units, etc.	1 2 3 4 5
11. I use graphic organizers (diagrams, flow-charts, etc) to better understand problems.	1 2 3 4 5
12. I experience moments of insight or creativity while solving problems.	1 2 3 4 5
13. I jot down things I know that might help me solve a problem, before attempting a solution.	1 2 3 4 5
14. I find important relations amongst the quantities, factors or	1 2 3 4 5

concepts involved before trying a solution.	
15. I make sure that my solution actually answers the question.	1 2 3 4 5
16. I plan how to solve a problem before I actually start solving it (even if it is a brief mental plan).	1 2 3 4 5
17. I reflect upon things I know that are relevant to a problem.	1 2 3 4 5
18. I analyse the steps of my plan and the appropriateness of each step.	1 2 3 4 5
19. I attempt to break down the problem to find the starting point.	1 2 3 4 5
20. I spend little time on problems for which I do not already have a set of solving rules or that I have not been taught before.	1 2 3 4 5
21. When I solve problems, I omit thinking of concepts before attempting a solution.	1 2 3 4 5
22. Once I know how to solve a type of problem, I put no more time in understanding the concepts involved.	1 2 3 4 5
23. I do not check that the answer makes sense.	1 2 3 4 5
24. If I do not know exactly how to solve a problem, I immediately try to guess the answer.	1 2 3 4 5
25. I start solving problems without having to read all the details of the statement.	1 2 3 4 5
26. I spend little time on problems I am not sure I can solve.	1 2 3 4 5
27. When practising, if a problem takes several attempts and I cannot get it right, I get someone to do it for me and I try to memorize the procedure.	1 2 3 4 5

Appendix 4

Students' semi-structured interview

I am going to ask you some questions about what you did while you were solving the chemistry problems which were given to you.

Planning

1. Did you always read the whole problem first before attempting to solve it? Why was this important/not important?
2. Do you sort out the information (into relevant and irrelevant) given in the problem? Why is this necessary/ unnecessary during problem-solving?
3. Describe the steps you would follow when solving a wordy (or long) problem.
4. When solving a numerical problem how do separate relevant from irrelevant data? (Possible response: I look at what the question requires me to calculate and then I choose the appropriate formula to use which helps me to identify the relevant data).

Monitoring

1. How often did you revise your solution as you worked through the problem? Can you give an example of when you did this and when you did not do this?
2. When solving a numerical problem it is necessary to check your steps as you work through the problem. How often do you do this? Give me example of when you did this and did not do this.
3. Did you always rate the difficulty of the problem e.g. this problem is hard/easy? Why was it important to do this?
4. Did you question yourself whether you are using the correct method while solving the problem? Explain why you did/did not do this.

Control

1. Do you think of a method to solve a problem before you attempt solving it?
2. How did you test the selected method to see if it was suitable for the problem task? How did you do this?
3. What did you do when you find out that you are using the wrong method?
4. Did you always ask other students or the teacher when you didn't know how to solve a problem? Explain

Evaluation

1. How do you check the effectiveness of your method?
2. How do you check the correctness of your solution to the problem?

3. How do you know that a solution is correct or wrong?
4. Why is it important to revise your procedure/method?

Motivation

1. How many of you believe that stoichiometry is difficult? Did you find the problem tasks difficult? (expectancy/affective)
2. Did you find the problem tasks interesting or boring? (*Don't tell me what you think I want to hear. Tell me the truth*). Explain(value).
3. Do you feel frustrated when you can't figure out how to approach a problem-solving task? (affective)
4. What do you do when you feel frustrated? (affective)

Appendix 5

Teachers' semi-structured interview questions

1. So how long have you been teaching the chemistry group that I have been working with?
2. Did you teach them stoichiometry?
3. Can you just talk me through how you teach stoichiometry i.e. what's your approach and how do you develop the topic?
4. Do you teach students to follow an algorithm?
5. Do you emphasize on conceptual understanding?
6. Do you advise students to remember the equations and to look at the interconnection between these equations?
7. Do you ask students to read the question and extract relevant information?
8. Do you advise students to stop and think (while solving a problem) if they are using the correct formula or the correct method
9. Do you encourage students to work together or to ask the teacher if they are in doubt or if they are stuck?
10. Do you deliberately combine students with different abilities to exploit joint cognition?
11. How do you motivate students?

Appendix 6

PRE-TEST PROBLEM-SOLVING TASK

20 grams of magnesium carbonate react with 25cm³ of hydrochloric acid at room temperature and pressure. Magnesium carbonate, is an inorganic salt that is a white solid. Several hydrated and basic forms of magnesium carbonate also exist as minerals. Magnesium carbonate is ordinarily obtained by mining the mineral magnesite. Magnesium carbonate can be prepared in laboratory by reaction between any soluble magnesium salt and sodium bicarbonate:



- Write a balanced equation for the reaction
- Describe and explain what is observed during the reaction
- Calculate the number of moles of magnesium carbonate that reacted
- A gas is formed during the reaction, calculate the volume of the gas formed during reaction.
- Calculate the mass of the salt formed in this reaction
- Estimate by calculation the concentration of the acid.

Appendix 7

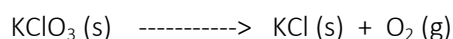
Teachers' practice problem-solving task

Instructions to the teacher of the experimental group

1. Teacher to introduce the metacognitive framework as a problem-solving aid.
2. Each student is given a copy of the metacognitive framework
3. Teacher to discuss with the students how to use the metacognitive framework to solve stoichiometry problems.
4. As the instructions on the metacognitive framework are self-explanatory, the teacher uses problem below to demonstrate to students how to use the metacognitive framework.

Practice chemistry problem

Potassium chlorate is an odourless, solid, fine crystalline, white coloured material. A word of caution about potassium chlorate is in order however. This material is a powerful oxidizing agent and **used** in making explosives, matches, and pyrotechnics. Oxygen gas can be produced by decomposing potassium chlorate using the reaction below. If 138.6 g of KClO_3 is heated and decomposes completely.



- a) Balance the equation
- b) Calculate the mass of KCl produced
- c) Calculate the number of moles of oxygen released during the reaction
- d) If the reaction was carried out under room temperature and pressure, determine the volume of oxygen released during the reaction.
- e) The potassium chloride produced was dissolved in 250cm^3 . Calculate the concentration of KCl.

Appendix 8

Post-test problem-solving task

Code name.....

Instructions: You will have 5 minutes to read and think about the question. After the reading time, you will have 10 minutes to think through the problem. You will then have up to 30 minutes to work on the problem individually and to complete the Metacognition Questionnaire. For the Problem-solving Task, please show all of your work and record your answers on the Answer Sheet using a pen.

A standard solution was prepared by dissolving 2.6061g of anhydrous sodium carbonate in distilled water and making up to 250cm³. A 25.0cm³ portion of this solution was titrated against hydrochloric acid, using methyl orange as indicator. This indicator changes colour when sodium carbonate has been converted into sodium chloride. 18.7cm³ of the acid were required for neutralisation. Answer the following questions. You will need to ask the teacher for extra data not provided in the question.

- Describe how you would prepare the standard solution above.
- Calculate the concentration of the standard solution.
- Write a balanced equation for the reaction that occurs during titration.
- Before there is change of colour what do you observe during the initial stages of titration?

Explain this observation.

- Write a balanced equation for the reaction.
- Calculate the concentration of hydrochloric acid.
- Calculate the volume of the gas released during the reaction given that the reaction takes
place at room temperature and pressure.

Appendix 9

Stoichiometric Problem-Solving Tasks

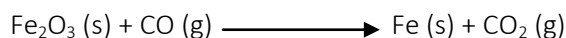
A- Lesson 1

1. The manufacturing of ammonia is carried out through the Haber process where hydrogen and nitrogen react in the presence of the iron(II) catalyst. The reaction ratio of nitrogen and hydrogen is 1:3 respectively.

- (a) Write a balanced equation for the reaction that form ammonia
- (b) What mass of NH_3 is formed from the reaction of 25.0 g of H_2 ?
- (c) What volume of N_2 at STP is required to react with 30.0 g of H_2 ?
- (d) How many molecules of NH_3 are produced from the reaction of 15.0 g of N_2 ?

B -Lesson 2

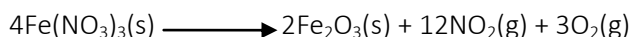
Iron is commercially produced by reacting iron(ii) oxide with carbon monoxide in the blast furnace. The following equation represents the reaction that produces iron in the blast furnace



- (a). Balance the above equation
- (b). Calculate the mass of CO needed to react completely with 50.0 g of Fe_2O_3 .
- (c). Calculate the mass of iron produced when 125 g of CO reacts completely.
- (d). Calculate the mass of CO_2 produced when 75.0 g of iron is produced.
- (e) Calculate volume of the CO_2 produced the reaction

C-Lesson 3

When heated, iron(III) nitrate ($M_r = 241.8$) is converted into iron(III) oxide, nitrogen dioxide and oxygen.



A 2.16 g sample of iron(III) nitrate was completely converted into the products shown.

- (a) (i) Calculate the amount, in moles, of iron(III) nitrate in the 2.16 g sample. Give your answer to 3 significant figures.
- (a) (ii) Calculate the amount, in moles, of oxygen gas produced in this reaction.

(a) (iii) Calculate the volume, in m^3 , of nitrogen dioxide gas at 293°C and 100 kPa produced from 2.16 g of iron(III) nitrate. The gas constant is $R = 8.31\text{ J K}^{-1}\text{ mol}^{-1}$. Use $pV=nRT$

(If you have been unable to obtain an answer to Question (a) (i), you may assume the number of moles of iron(III) nitrate is 0.00642 . This is not the correct answer.)

D-Lesson 4

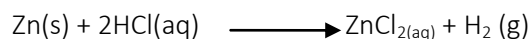
1. Zinc forms many different salts including zinc sulphate, zinc chloride and zinc fluoride.
2. (a) People who have a zinc deficiency can take hydrated zinc sulphate ($\text{ZnSO}_4 \cdot x\text{H}_2\text{O}$) as a dietary supplement.
A student heated 4.38 g of hydrated zinc sulphate and obtained 2.46 g of anhydrous zinc sulphate. Use these data to calculate the value of the integer x in $\text{ZnSO}_4 \cdot x\text{H}_2\text{O}$. Show your working.

2(b) Zinc chloride can be prepared in the laboratory by the reaction between zinc oxide and hydrochloric acid.

The equation for the reaction is $\text{ZnO(s)} + 2\text{HCl(aq)} \longrightarrow \text{ZnCl}_{2(\text{aq})} + \text{H}_2\text{O}$

A 0.0830 mol sample of pure zinc oxide was added to 100 cm^3 of 1.20 mol dm^{-3} hydrochloric acid. Calculate the maximum mass of anhydrous zinc chloride that could be obtained from the products of this reaction.

2(c) Zinc chloride can also be prepared in the laboratory by the reaction between zinc and hydrogen chloride gas.



An impure sample of zinc powder with a mass of 5.68 g was reacted with hydrogen chloride gas until the reaction was complete. The zinc chloride produced had a mass of 10.7 g .

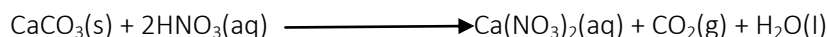
(d) Calculate the percentage purity of the zinc metal. Give your answer to 3 significant figures.

E-Lesson 5

Norgessalt peter was the first nitrogen fertiliser to be manufactured in Norway.

It has the formula $\text{Ca}(\text{NO}_3)_2$

(a) Norgessaltpeter can be made by the reaction of calcium carbonate with dilute nitric acid as shown by the following equation.



In an experiment, an excess of powdered calcium carbonate was added to 36.2 cm³ of 0.586 mol dm⁻³ nitric acid.

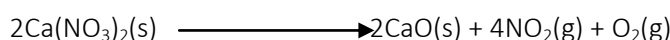
(a) (i) Calculate the amount, in moles, of HNO₃ in 36.2 cm³ of 0.586 mol dm⁻³ nitric acid. Give your answer to 3 significant figures.

(a) (ii) Calculate the amount, in moles, of CaCO₃ that reacted with the nitric acid. Give your answer to 3 significant figures.

(a) (iii) Calculate the minimum mass of powdered CaCO₃ that should be added to react with all of the nitric acid. Give your answer to 3 significant figures.

(a) (iv) State the type of reaction that occurs when calcium carbonate reacts with nitric acid.

(b) Norgessaltpeter decomposes on heating as shown by the following equation.



A sample of Norgessaltpeter was decomposed completely.

The gases produced occupied a volume of 3.50 × 10⁻³ m³ at a pressure of 100 kPa and a temperature of 31 °C. (The gas constant R = 8.31 J K⁻¹ mol⁻¹).

$$pV=nRT$$

(b) (i) Calculate the total amount, in moles, of gases produced.

(b) (ii) Hence calculate the amount, in moles, of oxygen produced.

(c) Hydrated calcium nitrate can be represented by the formula Ca(NO₃)₂·xH₂O where x is an integer.

A 6.04 g sample of Ca(NO₃)₂·xH₂O contains 1.84 g of water of crystallisation. Use this information to calculate a value for x. Show your working.

Appendix 10

LETTER OF INFORMATION TO PARTICIPANT STUDENTS AND PARENTS/GUARDIANS

Study Title: Investigating ways to help students solve A level chemistry problems involving stoichiometry.

Dear student,

I am undertaking this study as a course requirement for the Open University Doctorate in Education degree programme. I chose to study the impact of teaching methods on the enhancement of metacognitive skills during problem-solving in chemistry. Metacognitive skills involve thinking steps that you follow as you carry out a learning task such as problem-solving or planning an investigation. This study is concerned with different methods of teaching chemistry. Students who take part in the study will be randomly allocated to one of the three groups. One group will have extra tuition which is similar to your normal classroom teaching. The other two groups will have extra tuition which will include advice about the strategies that may help to solve chemistry problems. If one group is found to do better than others then students in the other group will be offered the opportunity to be taught using this method. When students agree to take part in the study they cannot be sure which group they will be in or whether they get more help.

The teaching is scheduled to run for three weeks and it has been designed to cover a topic which is generally considered to be challenging in A level chemistry courses. You will not be exposed to any risk during the study as does not involve any laboratory experiments. Participation is voluntary and you can choose to participate or not. These will be extra lessons and usual classroom lessons will not be affected. Lessons are scheduled to run after school for thirty minutes twice a week from 3:30-4:00 or at a time to be agreed with the school head and your teacher.

If the findings are published, no individual names or the name of the school will be mentioned in the study. You will be assigned pseudonyms to protect your identity. All information will be held securely and their name will not be entered in any computer records. Any data held on computer will be fully anonymised using code names that cannot be traced back to individual names. Any raw data will be kept under lock and key and shall be destroyed within 6-12 months. The key will be kept in safe. The study will involve interviews which will be recorded. Should you be chosen to for an interview at the end of the study, any recorded material shall not be disclosed to anyone else. The recorded interview shall be deleted after data been collected and this may take a few weeks. Any data collected from the interviews shall be anonymised. Your confidentiality will be protected in compliance with research ethics. You are free to withdraw from this research study at any time without giving reasons during the first week of the study. If you choose to withdraw after the first week, data collected will be included in the analyses. The research will be carried out in a normal science classroom and will be taught by one of the science teachers in the department. The research will be carried out in accordance with Ethical Guidelines for

Research Involving Human Participants in Zimbabwe. Should you desire to speak to someone else about my study please use the following contact: Professor David Messer (david.messer@open.ac.uk) who is supervising this project or

Director for Postgraduate Studies (CREET)

Dr. Tim Lewis (timothy.lewis@open.ac.uk)

The Open University, Walton Hall, Milton Keynes, MK7 6AA

Felix M Panganayi

Appendix 11

Informed consent form for parents

Please tick the appropriate boxes

Yes No

Taking Part

I have read and understood the study information sheet datedand have been given a copy of this information sheet to keep.

☐ ☐

I have been given the opportunity to ask questions about the project, the details of which have been explained to me.

☐ ☐

I agree to my child taking part in the project and committing the required time to the study. I consent to the researcher using the results as described in the information sheet.

☐ ☐

I understand that taking part in the project will also include my child being interviewed and audio-recorded. I consent to the researcher using the results as described in the information sheet.

☐ ☐

I understand that my child's participation is voluntary; and my child can withdraw from the study at any time and he/she does not have to give any reasons for why he/she no longer want to take part.

☐ ☐

Use of the information I provide for this project only

I understand that the confidentiality of the information provided by my child will be safeguarded and my child will not be referred to in any publication of the finding subject to any legal requirements.

☐ ☐

I consent to the 'test' scores of my child being shared with his or her teacher to assess progress

☐ ☐

I understand and agree that my child's anonymised data may be quoted and reproduced in publications, reports, web pages, and other research outputs.

☐ ☐

Parent/Guardian Name: _____ Date: _____

Signature of researcher : _____

Date: _____

Appendix 12

Informed consent form for participating students

Please tick the appropriate boxes

Yes No

Taking Part

I have read and understood the study information sheet datedand have been given a copy of this information sheet to keep.

☐ ☐

I have been given the opportunity to ask questions about the project, the details of which have been explained to me.

☐ ☐

I agree to take part in the project. I consent to the researcher using the results as described in the information sheet and I am willing to commit my time as stated on the information sheet.

☐ ☐

I understand that taking part in the project will also include being interviewed and audio-recorded. I consent to the researcher using the results as described in the information sheet.

☐ ☐

I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part.

☐ ☐

Use of the information I provide for this project only

I understand that the confidentiality of the information I provide will be safeguarded subject to any legal requirements.

☐ ☐

I understand and agree that my anonymised data may be quoted and reproduced in publications, reports, web pages, and other research outputs.

☐ ☐

Participant's Signature: _____ Date: _____

Parent/Guardian Name: _____ Date: _____

Signature of researcher : _____

Date: _____

Appendix 13

LETTER OF INFORMATION TO THE PARTICIPATING TEACHER

Study Title: Investigating ways to help students solve A level chemistry problems involving stoichiometry.

Dear teacher,

I am undertaking this study as a course requirement for the Open University Doctorate in Education degree programme. I chose to study the impact of teaching methods on the enhancement of metacognitive skills during problem-solving in chemistry. Metacognitive skills involve thinking steps that you follow as you carry out a learning task such as problem-solving or planning an investigation. I am requesting you to participate in this study to implement teaching strategies that enhance students' problem solving thinking skills. Some of these strategies are strategies that you may already be using in teaching routines

The study is scheduled to run for three weeks and it has been designed to help with stoichiometry which is a topic you are currently teaching. Participation is voluntary and students can choose to participate or not. During the study I will be monitoring how students use thinking strategies to solve Chemistry problems as they work in class. There might be audio or video recording during the study. This study is potentially beneficial to you as a teacher as you will explore and identify alternative teaching strategies that may be effective in developing and enhancing students' problem solving skills in Chemistry. You are free to decline taking part in this study.

If findings are published, no individual names or the name of the school will be mentioned in the study. You will be assigned a pseudonym to protect your identity. Your confidentiality will be protected in compliance with research ethics. All information will be held securely and your name will not be entered in any computer records. Any data held on computer will be fully anonymised using code names that cannot be traced back to individual names. You are free to withdraw from this research study at any time during first week without giving reasons. If you choose to withdraw after the first week, data collected from you will be included in the analyses. The research will be carried out in a normal science classroom during extra lessons time. Personal data will be kept secure under lock and key or password protected. The research will be carried out in accordance with the British Educational Research Association or the British Psychological Society. Should you desire to speak to someone else about my study please use the following contact: Professor David Messer (david.messer@open.ac.uk) who is supervising this project or Director for Postgraduate Studies (CREET) Dr. Tim Lewis (timothy.lewis@open.ac.uk)

The Open University, Walton Hall, Milton Keynes, MK7 6AA

Thank you for taking time to read this information sheet.

Felix M Panganayi

Appendix 14

Informed consent form for participating Teacher

Please tick the appropriate boxes

Yes No
S

Taking Part

I have read and understood the study information sheet datedand have been given a copy of this information sheet to keep.

☐ ☐

I have been given the opportunity to ask questions about the project, the details of which have been explained to me.

☐ ☐

I agree to take part in the project. I consent to the researcher using the results as described in the information sheet and I am willing to commit my time as stated on the information sheet.

☐ ☐

I understand that taking part in the project will also include being interviewed and audio-recorded. I consent to the researcher using the results as described in the information sheet.

☐ ☐

I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part.

☐ ☐

Use of the information I provide for this project only

I understand that the confidentiality of the information I provide will be safeguarded subject to any legal requirements.

☐ ☐

I understand and agree that my anonymised data may be quoted and reproduced in publications, reports, web pages, and other research outputs.

☐ ☐

Participant's Signature: _____ Date: _____

Name of Teacher : _____ Date: _____

Signature of researcher : _____

Date: _____

Appendix 15: Letter of information to the Head teacher

Study Title: Investigating ways to help students solve A level chemistry problems involving stoichiometry.

Dear Sir/Madam,

I am undertaking this study as a course requirement for the Open University Doctorate in Education degree programme. I chose to study the impact of teaching methods on the enhancement of metacognitive skills during problem-solving in chemistry. Metacognitive skills involve thinking steps that you follow as you carry out a learning task such as problem-solving or planning an investigation. A teacher will teach students thinking strategies employed in problem solving in chemistry for one hour three times a week. The study is planned to make use of the content that will be under study in the normal teaching cycle, so there shouldn't be any significant disruption to the teaching and learning routine. No special changes will be required in order to accommodate the study. All participating students stand a good chance to benefit from the study and skills acquired will serve students well beyond their 'A'-level studies.

The study is scheduled to run for twelve weeks and it has been designed to incorporate learning content which is part of the students' course of programme in order to minimise undue adverse impact on learning. The students will not be exposed to any risk during the study. Participation is voluntary and students can choose to participate or not. Students will be taught by teachers who volunteer to participate in the study. During the study I will be monitoring how students use thinking strategies to solve Chemistry problems as they work in selected pairs. No audio or video recording will be carried out during the study.

If the findings are published, no individual names will be mentioned in the study. Students will be assigned pseudonyms to protect their identity. Students' confidentiality will be protected in compliance with research ethics. The students are free to withdraw from this research study at any time without giving reasons. The research will be carried out in a normal science classroom and will be taught by one of the science teachers in the department and will take place in the afternoon after school. The research will be carried out in accordance with the British Educational Research Association or the British Psychological Society. Should you desire to speak to someone else about my research please use the following contact: Professor David Messer (david.messer@open.ac.uk) who is supervising this project or

Director of Postgraduate Studies (CREET)

Dr. Tim Lewis (timothy.lewis@open.ac.uk)

The Open University, Walton Hall, Milton Keynes, MK7 6AA

Yours Sincerely,
Felix M Panganayi

Appendix 16: Questions and responses on planning

Questions	Group A	Group B	Group C
Did you <u>always</u> read the <i>whole</i> problem first? Did you sort out the information needed?	Ru: 'I will read the entire question, so that I don't have to keep referring back to the question'	B: Yes, I always read the whole question D: I read the whole question then pick the information which is relevant.	P, K, N, S: Yes
Reads whole question + Gives reasons for this	Ru: 'I will read the entire question, so that I don't have to keep referring back to the question'	D: I read the whole question then pick the information which is relevant.	S: Yes, to avoid mistakes K: And to extract as much information as quickly which the question has asked for P: I think for me it is to understand the whole question P: To understand the situation and apply some of the information I have read before adding any other things which may not be required in the question.
Does not read the whole question	All said they read the whole question	T: No, I only looked for the key points, like if there was like concentration M: Yes, sometimes it depends if like I know what's coming or what they are going to ask I don't read the whole question but if I don't get the first part then I will try and read the whole question to understand it. Sometimes I just get started on the first bit and then do the rest	J: Not always, well I just like, I look at the question and then I think I just figure out what I need to do at times
If it's a long question how would you approach it?	J: First you have to read the whole question and then sort it into groups depending on the information provided, you go back and start dividing it into groups e.g. if it's about calculating number of moles, concentration etc..	S: Sometimes I would read the whole question and then, like at least once and then I go back and break into parts and start working on each part. B: I will read the whole question to see what's needed and then jump to whatever the question wants (me to do). D: I read the whole question then pick the information which is relevant.	K: Well if it's a long question probably its asking for you to calculate concentration for example, it might give you volume and number of moles, so first we have like a method we use, just like changing formula in maths, so we extract those like just one by one and try to break it down as much as possible just to try and avoid mistakes.
After reading a question and before attempting to solve a problem, do you actually think about what method or formula to use?	All students say they think about how to approach the question in term of strategy e.g. thinking of an appropriate formula to use.	S: It's like when you are reading a question before you fully understand it may be some ideas can come to you ok like, I think I need to do this or I need to do this one, yeah and then try one, then you see that after you have understood the question you can then see that perhaps you were wrong, then you can go back and change it.	All students say yes. K: Well if it's a long question probably its asking for you to calculate concentration for example, it might give you volume and number of moles, so first we have like a method we use, just like changing formula in maths, so we extract those like just one by one and try to break it down as much as possible just to try and avoid errors.

Appendix 17: Questions and responses on monitoring

Questions	Group A	Group	Group C
Let's say you are solving a numerical problem, is it necessary to check the steps that you are going through as you solve the problem and why?	R: says she does go back to check on her steps to ensure that she is on the right track.	But if it's like a, b and c right, and then I did a and b, but c is coming from a and b and c is looking wrong then I have to back to see if I did a and b correctly	N: It depends, if the question was hard I would have to go back and make sure that I have done everything right and if that easy I would not go back to check.
Does not revise steps while solving a problem task and gives reasons.	J says he does not always go back to review the correctness of what he is doing... 'if one goes back to check the steps immediately after completing the problem, one may not be able to spot the error'.	T: I don't revise at all: because I took so much time writing and working out, so I just feel like all that energy, the answer is either right or wrong, there is no more space to work out again.	P: No, not all the time because if you use the method that you have, you will be so sure that no there will be no time to go back, so may be at the end of the whole question.
Do yourself of the correctness of your strategy or method that you are using while solving a stoichiometry problem?	All students except one say that they do not question the correctness of their method while solving a stoichiometry problem. Student F says, 'if you start questioning the correctness of the method you can begin to doubt and may end up changing the correct thing in the process'	S: I do it a lot actually because sometimes like, most of the time when I was doing my work previously I would make a lot of silly mistakes, but these days I am a bit careful. M: I do ask myself, but I don't think I go over the work and stuff, I don't think I do it enough to check if the answer is correct TN: I do it only when revising work D: I ask myself all the time and usually I go to the textbook to look for worked examples B: Anything that involves formulas and figures I do ask myself if I am doing it right.	All: Mixed reaction some saying no. K: Ah I always ask myself because it's a must to know the correct method so yeah.
Did you always rate the difficulty of the problem e.g. this problem is hard/easy?	Mixed responses. Some say if the question is hard or easy they will know it after reading it.	T: I think once you just read the question automatically you know that I know this, or I don't know this or you just know this is difficult or this is easy.	P: I always do that because it depends on the question is actually easy I could say 'oh I must have gotten this correct' and if hard then oh man I wasn't sure, let me just put my work in. K: Yes I always do thatJ: Ummm well it depends on how I feel at that moment.

Appendix 18: Questions and responses on control

Questions	Group A: Avondale	Group B: Eastly	Group C: St. John's
What do you do when you find out that the method you are using is incorrect? Has this happened to you?	F: I think of another method Others agree	B: I just jump to my neighbour to see what have they done. Yes D: I will check from the textbook, maybe I would have forgotten the equations so I will go back to the equation and check if the equations are correct then I enter the information that is in the question. M: I think you should ask advice from someone who is like, ah like the teacher or look up for a worked example from the textbook.	J: When it's really hard when I am in class usually in a lesson, if I don't ask I will try to solve it when I am studying at home. P: I will try to check some information in the book and if I see that the information in the book is difficult to understand then I will seek help from my colleagues and then if my friends don't know how to help then I will go and ask the teacher. S: It's like I ask for clues then I try to solve it myself all the time.
How do you think of another method?	Ru: If it involves equations, you need to think of another equation that relates to the information you are given.	Response is same as above	Response is same as above
Do you for example, ask your neighbour, the teacher or do you consult the textbook?	All students say they consult the book. They do not consult their neighbour nor their teacher	D: I will check from the textbook. TN: Usually I just ask someone else to help me.	S: It's like I ask for clues then I try to solve it myself all the time. P: I ask him (<i>pointing to S</i>)
Consults the textbook Asks another student Asks the teacher	Ru says that she sometimes consults the teacher.	D: Yes TN: Yes	Same as above
Gives reasons why he/she does not consult teacher or other students	They say they do not consult their neighbours because they are afraid of being misled as their neighbour may be experiencing the same difficulties (<i>absence of the appreciation of the power of joint cognition</i>). They do not ask the teacher and they all laugh .	T: No, I feel like if I found it (the question) difficult then the next person may have found it difficult too. T: No, I won't even ask the teacher I just move on.	J: When it's really hard when I am in class usually in a lesson, if I don't ask I will try to solve it when I am studying at home.

Appendix 19: Questions and responses on evaluation

Questions	Group A: Avondale	Group B: Eastly	Group C: St. John's
How do you check the effectiveness of your method? By effectiveness I mean the method that gives you the correct answer.	J: I can try to prove it mathematically, i.e. I try to calculate reverse wise. CT: I will go to the text book to check for an appropriate approach to use. The textbook has all the information I need, and I just need to follow its examples	T: You use the back method All: Seem to think that carrying out an arithmetic proof checking is the best way to check accuracy of a numerical solution	Se: I work it out to the same, like finding the number which is given right, to the answer I got. Like if you want concentration, if you then change it to find the number of moles which you were given with the concentration you got. All: we agree
How do you check the correctness of the solution to the problem? For example, do you compare your solution with that of your peers?	M : I do not check the reliability of the answer J: I try to prove it mathematically Others: We ask others	S: Yeah ok if not in the exam yes I can compare (<i>with someone else's answer</i>), but sometimes you have too much confidence and pride and then you don't ask. B: If you trust the person you can compare your answer with theirs T: But if you know that this person is no good in chemistry and half the time in those topics they are getting it wrong then I don't feel comfortable to ask them. But if people I do trust I can ask.	All say they use mathematical proof K: I check with his answer (<i>pointing to Sean</i>) K: Yeah, I admire his intelligence N: Yes, I usually check in a textbook, if the answers are different I go back to my textbook and check with the known facts and then I compare her method with my method to see if one has mixed up stuff. All agree
Why is it important to review your strategy or your method?	F: To make sure that you are correct and that you are going in the right direction. It also helps to spot errors made during the calculation. Other students agree	S: Sometimes you can think of a method that has an equation that has two unknowns or has something that you are not given, so you have to think of another equation that satisfies the one that you are not given. T: Sometimes you can confuse the question with another one or can answer another question, like they are asking about titration and you are answering precipitation, so you have to break the question down S: It makes life easier, because you don't have to use formulas that will make you look silly	Se: But if it's like a, b and c right, and then I did a and b, but c is coming from a and b and c is looking wrong then I have to back to see if did a and b correctly. K: If b and c are looking very impossible, yeah, you will have to go back and check a All agree

Appendix 20: Questions and responses on motivation

Questions	Group A: Avondale	Group B: Eastly	Group C: St. John's
<p>Affective How many of you believe that stoichiometry is difficult?</p> <p>Expectancy/Affective Did you find the problem tasks difficult?</p>	<p>Mixed responses, but generally all believe it's a difficult topic in chemistry. R says 'it depends on how the question is structured. It is more to do with identifying the relevant information especially from long questions.'</p>	<p>All agree that its a difficult topic</p> <p>T: It's the hardest topic in chemistry, that's just plain simple.</p>	<p>K: They were challenging, so yeah for me for the first time the first exercise was very difficult. When I got home I opened the textbook and started reading, but then for the second exercise it was pretty good because I now had some information as to how to calculate especially the stoichiometry ratio which I didn't understand, but now I actually understand how to use the stoichiometry ratio. And for the concentration eh I found it hard.</p>
<p>Affective Did you find the problem tasks interesting or boring? (Don't tell me what you think I want to hear. Tell me the truth) Explain</p>	<p>All: They were fine</p> <p>F: I learnt something</p>	<p>B: Yeah I did, I even invented my own formula S: Yeah T: I don't think they were boring because they were short structured and I was like ok if I get this one right I have got three other M: Yes in the end D: Yes</p>	<p>N: I found it very interesting because for the first exercise I made a mistake on my A, that's when the a, b, c sections were wrong so, that's when I learnt that you have to go over it again to make sure that everything is right to avoid silly mistakes, yeah so I learnt something. K: They were challenging, so yeah for me for the first time the first exercise was very difficult but then for the second exercise it was pretty good because I now had some information as to how to calculate especially the stoichiometry ratio which I didn't understand, but now I actually understand how to use the stoichiometry ratio.</p>
<p>Affective/Value Do you feel frustrated when you can't figure out how to approach a problem-solving task?</p>	<p>All: Yes</p>	<p>M: Yeah, sometimes I feel discouraged, but because I feel like if I don't work it out then I am stuck, there is nothing I can do about it so yeah.</p>	<p>All: Yes</p>
<p>Value What do you do when you feel frustrated?</p>	<p>Student Ru says 'I don't feel frustrated rather I think of another method' question' Ro: I can then ask for help from my colleagues or look up from the textbook or ask the teacher Student F says 'I try to keep cool and think of a different way to approach the question'</p>	<p>S: I feel challenged because, ah, let's say it's difficult for me and then I think, oh maybe it's difficult for someone else right, and then I try this question and I get it right and maybe I am the only person who gets it right,... it's not.. yeah it's something that pressures me and maybe you are the only person who can get it right, yeah so just try it. TN: I feel encouraged to try and solve the problem D: I get discouraged and I just skip it.</p>	<p>J: I try to relax, because if I don't like my mind is overheating or something. I relax, move on and then I come to it. N: First I feel frustrated and then I will tell myself and say well if someone could come up with this question he can definitively answer it. I will probably take a day just to relax and then come back to it the next day and I will read the textbook. I will go over the textbook again and again just to check what am I missing, then I will go back to the question</p>

Appendix 21: Questions and teachers' responses/comments

	Teacher A	Teacher B	Teacher C
Teaching experience	11	15	18
So how long have you been teaching the chemistry group that I have been working with?	I started teaching them this year.	Yes, from last year	I just got them this year
Did you teach them stoichiometry?	Unfortunately that topic of stoichiometry was taught by another teacher before I took over the group. So you might have observed some discrepancies between what I am telling you now and the way the students performed during your sessions with them.	Yes	I had to teach the topic again because they were not confident enough and they thought it was a difficult topic, so I went over it again.
Can you just talk me through how you teach stoichiometry i.e. what's your approach and how do you develop the topic?	Well for me the first important thing is to introduce the students to deriving formulas of compounds and to know the chemical symbols of elements. The important thing in stoichiometry is to know the chemical formula so that you can write the chemical equations. And from the chemical equations you can then derive certain pieces of information that are needed to do calculations.	<p>Stoichiometry is quite a broad topic involving a lot of calculations. But what I normally do is to start with simple calculations involving for example empirical formula, percentage composition, relative formula mass etc. These are just simple calculations which are procedural.</p> <p>In other words they are algorithmic there is little reasoning involved. For example if they are calculating empirical formula when given percentage composition it's just step 1: divide by the A_r, step 2: divide by the smallest ratio and step 3: compare the ratios to obtain the empirical formula. These are relatively simple calculations. Now when it comes to the actual stoichiometry, the ratios when you want students to link ratios in an equation. Because there are a lot of formulas that are involved and when you give students the formulas sometimes there is a tendency to misuse the formulas. For example if you give them a formula for calculating the number of moles for gases, now because the formula involves volume, when a student is confronted with a problem that requires calculation of</p>	Basically I have broken it down to.... starting from what they know from the two previous years i.e. form 1 (Yr8) and form 2 (Yr9), like there are three states of matter solids, liquids and gases. I then break down moles, like there are moles for solids, liquids and gases. Solids have got elements and compounds. So moles for solids could be mass/relative atomic mass (m/A_r) for solid elements and for solid compounds it would be mass/relative molecular mass (m/M_r) and for gases I tell them that there is molar volume for the gas and I give them the formula or the equation to go with it. I then give them examples of reactions for example, the reaction of carbonates with acids like the reaction of sodium carbonate with hydrochloric acid to give the salt, carbon dioxide and water. So from this students can see that they can obtain substances with different states in the same equation. They can calculate the number of moles of a gas and a solid. For the liquids I start from solute and solvent and tell students that solute and solvent will give a solution. So they appreciate that when a solid dissolves in water it forms a solution. For example we can weigh 5g of sodium hydroxide and put them into a volumetric flask and dissolve it and then top it up to the 250cm ³ mark. I can then ask the students to calculate the concentration of the solution. In this case the students calculate the number of moles of the solute (sodium hydroxide) using m/M_r and then divide the number of moles with the volume to get concentration (n/V).

		<p>number of moles of a substance in solution form they may apply the formula used to calculate moles of gasses. The same misuse of formula can happen conversely.</p>	
<p>Do you teach students to follow an algorithm?</p>		<p>So my approach that I think has helped students in solving stoichiometry problems is to think of four steps in solving any stoichiometry problem: You need to come up with a balanced equation. This is a prerequisite (Be able to) Calculate the number of moles of any substance in the equation What is the stoichiometric relationship between the substance whose number of moles you have calculated and the substance whose number of moles you want to calculate? When you know that ratio it means you can calculate the moles of the other substance. Use the calculated moles to find the required quantity. For example let's say you are given the reaction between magnesium and hydrochloric acid to give magnesium chloride and hydrogen gas given that there are 6g of magnesium that reacted with excess hydrochloric acid of concentration 2mol dm^{-3}. So what can you calculate? You can calculate the number of mols of Mg but you cannot calculate the number of moles of HCl that reacted. So once you calculate the number of moles of Mg it means you can get the number moles of any other substance in the equation. Then you can go back to the formula</p>	<p>I just break down everything into sequential order that follows the order of concepts like I said before; they have to know the three states of matter and they have to be able to calculate the number of moles. So they have to understand the mole concept and this is related to writing of balanced chemical equations, starting from the formula of a compound to writing the equation and balancing the equation. And why do we have to do this? Because balancing the equation tells us the molar ratios of both reactants and products and this is what stoichiometry is all about. It is the relationship between the moles of substance in the balanced equation.</p>

		and see what you are required to calculate. Is it the volume of hydrogen? If so, what's the relationship between the volume of hydrogen and the number of moles of hydrogen since you already have the number of moles of hydrogen?	
Do you emphasize on conceptual understanding?	I think from my experience, the main challenge is that they forget the chemical formulas of compounds taught and for some students it has to do with how the topic was taught when students were first introduced to stoichiometry. A good foundation provides a good understanding of the basics of the topic. If the students are taught chemical bonding first and then introduce them to the formula and the calculations it's much easier for the students to understand the topic and be competent to handle the stoichiometry problems. If the teacher fails to teach the basic concepts of stoichiometry then it becomes difficult for students understand the topic. I believe that if the students are not taught well the basic concepts of stoichiometry then the students will resort to memorising the formulas without being able to derive them from the underlying concepts and rote learning will not help students to be competent enough to solve stoichiometry problems.	It is lack of conceptual understanding. What I normally do when I introduce formula, for example m/M_r or m/A_r , I specify in bold ' never use this formula for substances that are not pure. Don't use this for solutions, impure samples, etc' '. But of course misconceptions do surface for example when given a sample of an impure substance and required to calculate percentage purity, you find that the student uses the mass of the impure substance to calculate the number of moles. Yea, so in summary normally I teach stoichiometry, I start by teaching the simple concepts and then go step by step to more complex concepts and processes. It's a topic that needs a lot of time and practise.	Yes, they need to understand the concepts because if they don't understand the concepts then cannot solve the stoichiometry problems because if they get a question where do they start when they do not understand? They think the question is difficult....like I have this and I have that what can I do with this information, what can I calculate from this? If they simply memorise without understanding then confronted with a problem then they won't even understand what the question requires then to do. So I emphasize on understanding the basic ideas and concepts and then applying these to solve stoichiometry problems.
Do you advise students to remember the equations and to look at the interconnection between these equations?	Yes I actually encourage them. There are of course certain formulas which are associated with certain types of problems. For example if dealing with the solid substances and one is required to calculate number of moles. The formula that is required is different from the one required for calculating the number of moles of substance in solution form		Well like for the moles $n=CV$ will be simple to remember. So it's just giving them mnemonics as well. I don't really encourage them to use the triangle approach because I believe they can get confused. Yes, from the units mol dm^{-3} they can relate to what they know like from speed = distance/time could be given in km/hr, so when they see this they can remember that they are dividing distance by time. The same with mol dm^{-3} they can see that they need to divide moles by volume to get concentration. They can work out index from their knowledge of indices in maths. If they remember the units they can never be stuck for a formula.

<p>Do you ask students to read the question and extract relevant information?</p> <p>Do you advise students to stop and think (while solving a problem) if they are using the correct formula or the correct method?</p>	<p>Yes such techniques are important and maybe we do it differently. I ask the students to use the information given in the question. The student must understand the question first and pick up certain pieces of information from the problem which I think it's the same as telling the student that they have to read the question first and use the information provided. For a wordy question I tell them that they must read the question first and find out what information is given, identify the pieces of information provided which are required for solving the problem.</p> <p>I wouldn't say I encourage them to revise as they are solving the problem. I encourage them to revise when they have finished the whole question and make any corrections. No, I don't really encourage them to review step by step or section by section.</p>	<p>At IGCSE such problems are not that many. At this level most stoichiometry problems are broken down for example they be asked to calculate percentage yield, the question is broken down into moles this and moles of that, which makes it straightforward for the students extract information. But at A level this is where long questions with irrelevant information are found. <i>However I encourage the students to extract numerical information given in the question and then decide which equation to use. Yes, read the question and extract the relevant information first</i> for example this is HCl right, what am I given for HCl? Maybe I am given the volume and concentration. I could also be given the mass of magnesium and I am also given the temperature, but is the temperature necessary? I have to decide that.</p>	<p><i>I always tell them that when they get a question (stoichiometry) underline what information you are given in the question and also underline what you have been asked to find and that way then you are able to tease out.</i></p> <p>If it's board work where I can pick a student to go to the board to solve a problem, if anything goes wrong I can ask them they revise what the student is doing and I can ask them like 'what the best way to proceed with that calculation etc. But when they do it individually it's difficult to monitor.</p>
Do you model how to solve problems through board work to allow students to be able to do individual work?	I demonstrate on the board using a worked example	I demonstrate through an example on the board	Yes, I first show them how to solve the problem so that they can follow the format in a sequential way.
Do you encourage students to work together or to ask the teacher if they are in doubt or if they are stuck?	I do encourage them and like I said before we do encourage active participation of students and I believe that encouraging students to work together sharing information encourages peer education where students learn from each other. It also enables the student whoever has been teaching others to consolidate or cement what he/she would have learnt.	Yes in class they can consult each other or the textbook or the teacher Uhhmm I can't say I deliberately do that. But when they are working in class they sit in pairs and they work together. What I do tell them is that if they are trying to solve a problem and they are stuck and don't know where to start, they can raise their hands to ask for help from me	I put them into groups for collaborative working because working alone can sometimes be frightening and if they are working individually confidence levels may be low because they think, 'am I doing the right thing or no'. But if they consult each other they can have a discussion and have a joint effort in completing the problem task. When making up the groups, I choose those students whom I know have a better understanding of the task together with those who may be struggling with the problem tasks. I don't just put the groups at random. They are meant to benefit each student.
Do you deliberately combine students with different abilities to exploit joint cognition?	No	No.	Yes I combine students with different abilities so that the fear of failure at individual level is reduced, because when they work as a group it gives confidence to the less able and there is collective responsibility as a group. There are opportunities of peer tutoring when students of mixed abilities

			work together. When students learn from each other it's less intimidating to ask each other when they don't understand than if they were to ask the teacher, because the student might think that they are the only one not getting it and they have to ask the teacher when the whole is quiet and listening to them asking for help from the teacher
How do you motivate students?	Motivation is important not only in chemistry but across all subjects. It is through the interest, attitude that the student has that will determine whether the student understands the subject or topic that they are learning. So it's not only limited to chemistry or stoichiometry alone, I noticed that motivation matters to other subjects as well. If students are to perform well, they need to love what they are learning and this will enable them to actively participate in learning the subject. There is also the general belief among students that mathematics is difficult, now when mathematics (a difficult subject already) is now being applied to stoichiometry a difficult topic it makes it even more difficult.	<p>I start by giving students simple problem tasks which they do not struggle with. This helps to build their confidence which allows them to transit to more challenging problem tasks.</p> <p>I give them achievement targets which they should achieve and when they achieve these targets we celebrate and compliment those who achieve their targets. The targets are however differentiated so that each student is able to work at their own level.</p>	I wouldn't say I do anything special, but it's simply giving them encouragement. It's about showing care and concern for students. For example one of my students on the group that you interviewed struggled with her English and I had to tell her that unless she improved on her English understanding chemistry was going to be difficult for her. She took my advice on board and now she has made tremendous improvement and she is now quite confident. She now can contribute to class discussions and yet before she was reserved and so quiet that you wouldn't see her. I use whole class activities to boost their confidence by asking them maybe to go to the board to do a task they can do. I also have a good knowledge of my students' individual circumstances for example if they are orphaned or maybe they are having a difficult time at home or at school. I show them that I am interested and concerned about them as students.